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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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A GENERAL TANK TEST OF N.A.C.A. MODEL 11-C FLYING-BOAT HULL, INCLUDING THE EFFECT OF CHANGING THE PLAN FORM OF THE STEP

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SUMMARY

The results of a general tank test of N.A.C.A. model 11-C, a conventional pointed afterbody type of flying-boat hull, are given in tables and curves. These results are compared with the results of tests on model 11-A, from which model 11-C was derived, and it is found that the resistance of model 11-C is somewhat greater.

The effect of changing the plan form of the step on model 11-C is shown from the results of tests made with three swallow-tail and three pointed steps formed by altering the original step of the model. These results show only minor differences from the results obtained with the original model.

INTRODUCTION

Although model 11-A (reference 1) showed very good resistance characteristics, it was believed that the shape of the bow could be improved to give better seaworthiness without greatly increasing the resistance. Accordingly, a new set of lines was laid out incorporating this change and the model made from them was designated model 11-C.

This model, which is fairly representative of the type most common in American flying-boat practice, was used to determine the effect of changing the depth of step (reference 2) and the effect of changing the angle of afterbody keel (reference 3).

Although a number of flying boats have incorporated main steps that do not have the conventional straight line plan form, there is a scarcity of data on the effect of

these changes on the water performance of the hulls. Results of tank tests on three pointed-step hulls developed at the N.A.C.A. tank have been published (references 4 and 5) but these hulls have forms that differ radically from the forms of conventional hulls now in use. In order to provide data concerning the effect of changing the plan form of the step on a conventional flying-boat hull it was decided to make tests of model 11-C with several alterations in the plan form of the step.

THE MODEL

The principal lines of model 11-C are shown in figure 1 and the offsets are given in table I. A direct comparison between the forebodies of model 11-C and model 11-A can be made with the aid of figure 2. In this figure the base line of model 11-A is lowered to make the chines of the two models coincide at the step. It is seen that aft of station 7 the only difference in the bottoms of the two forebodies is at the keel, where the sections of 11-A are brought to a point and those of 11-C are not. The flat keel formed on model 11-C more nearly conforms to existing structural practice than does the sharp keel of model 11-A. Forward of station 7 the keel and buttocks of model 11-C rise more rapidly than do those of model 11-A; furthermore, the water lines of model 11-C are finer and the sections have considerably more curvature. The afterbodies of models 11-C and 11-A differ only at the keel where model 11-C has a small transverse flat and the sections of model 11-A are brought to a point.

Model 11-C was altered by changing the plan form of the step as shown in figures 3 and 4. Tests were made with six variations designated by the acute angle between the lines forming the swallow tail or point and the line of the original step (i.e., 15° swallow-tail step, 15° pointed step, etc.). The depth of step for the swallow-tail and pointed steps is not uniform but the mean depth of step in all cases is the same as for model 11-C.

Following N.A.C.A. tank practice the model was made of laminated wood sanded, painted, and rubbed to give a smooth surface. The different steps were formed by inserting blocks into a removable portion of the model.

APPARATUS AND PROCEDURE

The N.A.C.A. tank, its towing carriage, dynamometer, and other equipment are described in reference 6. With the exception of the moment-measuring apparatus the present towing gear is similar to the one described in reference 7. In the present gear the trimming moments are measured by a very stiff spring whose deflections are indicated by a dial gage.

All the models were tested by the "general" test method described in reference 8. This method consists of towing the model at several fixed trim angles with a number of constant loads over a wide range of speeds. Tests are made at a sufficient number of trim angles to determine the trim angle that gives minimum resistance for every load and speed in the range tested.

The swallow-tail and pointed-step variations were tested over a considerably smaller range of speeds and loads than model 11-C, because the tests on the former were intended only to show the effects of the changes made; the effects outside the range tested may be inferred from the trend of the curves.

RESULTS

Test Data

Curves of water resistance (includes air drag of model) and trimming moment plotted against speed for each of the trim angles used are given in figures 5 to 10 for model 11-C and in figures 11 to 22 for the 30° swallow-tail and 45° pointed-step variations. Trimming moments which tend to raise the bow are considered positive to conform with the usual aerodynamic convention.

Curves of test data for the 15° swallow-tail and the 15° and 30° pointed steps are not included because it is believed that the curves of resistance coefficient at best trim angle are sufficient to show the small effects of these variations of the step.

No data for the 45° swallow-tail step are given as it soon proved to be impracticable because of the extremely shallow depth of the step at the keel. The effect was the

same as that encountered in tests of a model having a conventional type of step with too little depth (reference 2).

Curves of trimming moment against trim angle with load as parameter, and draft against load with trim angle as parameter for the model at rest are given in figure 23 for model 11-C. These curves, plotted from tank data, permit the determination of the water line at rest for a wide range of loads and center-of-gravity positions without the laborious calculations necessary to determine the water line from the lines of the hull.

Nondimensional Data

The trim-angle variable is eliminated as in reference 8 by determining the trim angle which gives minimum resistance. The minimum resistance, speed, load, and trimming moment required to obtain the trim angle for minimum resistance, are converted to the following nondimensional coefficients.

Speed coefficient, $C_V = \dfrac{V}{\sqrt{gb}}$

Load coefficient, $C_\Delta = \dfrac{\Delta}{wb^3}$

Resistance coefficient, $C_R = \dfrac{R}{wb^3}$

Trimming-moment coefficient, $C_M = \dfrac{M}{wb^4}$

where V is speed, ft./sec.

g, acceleration of gravity, ft./sec.^{2}

b, maximum beam of hull, ft.

Δ, load on water, lb.

W, specific weight of water, lb./cu.ft. (W = 63.5 lb./cu.ft. for the water in the N.A.C.A. tank during these tests)

R, resistance, lb.

M, trimming moment, lb.-ft.

Any other consistent set of units may, of course, be used.

At the lowest speeds this method was not applicable to model 11-C for the curves of resistance against trim angle did not consistently show a minimum resistance. In this region, however, the resistance does not vary greatly with trim angle. Therefore, up to $C_V = 1.6$, the free-to-trim (zero trimming moment) resistance and trim angle were used for model 11-C.

The nondimensional data for model 11-C are plotted in figures 24 to 27. Values of C_R are plotted against C_V with C_Δ as parameter in figure 24 and against C_Δ with C_V as parameter in figure 25. Figure 24 is more easily interpreted but figure 25 is more readily used in take-off calculations (reference 8). Values of τ_o (best trim angle) and τ_F (trim angle for zero moment) are plotted against C_V with C_Δ as parameter in figure 26. Trimming-moment coefficient C_M is plotted against C_V with C_Δ as parameter in figure 27.

In figures 28 to 32 C_R at best trim angle is plotted against C_V with C_Δ as parameter for the swallow-tail and pointed-step variations. No other nondimensional data are given for these changes as the effect of the variations on the other nondimensional coefficients is practically negligible.

DISCUSSION OF RESULTS

It was thought that the differences in form between model 11-C and 11-A would not seriously affect the resistance, but the results of these tests indicate that model 11-C has somewhat greater resistance than model 11-A at the hump, although only small differences were obtained at high speeds. In figure 33 values of the load/resistance ratio (Δ/R) for best trim angle are plotted against C_Δ for several values of C_V for both model 11-A and model 11-C. It seems best to make comparisons between tests made on the same type of towing gear so that Δ/R values for model 11-A are taken from recent tests made with the present type of towing gear and differ somewhat from the results of the original test of this model given in reference 1.

From figure 33 it is seen that model 11-A has considerably better Δ/R values at the hump than has model 11-C. This difference decreases with increasing speed and decreasing load until at $C_V = 6.0$ the differences in the values of Δ/R for the two models are negligible. It thus appears that the penalty paid for changing the bow is an increase in hump resistance.

In figure 34(a) the maximum positive trimming-moment coefficients of models 11-A and 11-C are compared. The centers of moments used in the tests of these models were different but C_M values for model 11-A have been converted to the same center of moments used in the tests of model 11-C. Although the maximum positive C_M is consistently greater for model 11-A than for model 11-C the difference is primarily due to the difference in best trim angles obtained for the two models as illustrated in figure 34(b). As the difference in the best trim angle of the two models is within the accuracy to which this variable may be determined, the difference between the maximum positive moments of the two models is negligible. The moments at high speeds for the two models are not compared here because they are not very large and, with the increased aerodynamic moments available at high speeds, they become relatively unimportant.

A comparison of the best angle Δ/R values of model 11-C, the 45° pointed-step model, and the 30° swallow-tail step model is shown in figure 35. The differences shown at the hump and at $C_V = 6.0$ are of the order of the accuracy of the tests. At $C_V = 4.5$ the differences are very small at the light loads but become quite appreciable at the heavier loads where both the 45° pointed step and the 30° swallow-tail step show considerably lower values of Δ/R than does model 11-C. This region is of only minor importance in take-off problems as it lies between the hump and the high-speed critical region. The other step variations produced similar effects.

A comparison of the curves of test data shows that the maximum positive trimming moments were not greatly changed by the changes in the plan form of the step. Differences in these maximum values are attributed to the rather wide spacing of test points in the swallow-tail and pointed-step series.

Between 10 and 13 feet per second with 100- and 120-pound loads, model 11-C was directionally unstable and

none of the swallow-tail or pointed steps corrected this condition. It is, however, doubtful whether this trait would prove very detrimental in an actual flying boat as the region would be quickly passed through during take-off.

Representative spray pictures of models 11-C and 11-A are shown in figure 36 for the 100-pound load. Model 11-C appears to have slightly better spray characteristics.

CONCLUDING REMARKS

The water resistance of model 11-C is greater than that of 11-A for all loads at the hump but there is little difference in the high-speed resistance of the two models.

The spray characteristics of model 11-C are somewhat better than those of 11-A and, on the whole, they are quite satisfactory.

With the exception of the 45° swallow-tail step, which is impracticable because of the small depth of step at the keel, the swallow-tail and pointed steps do not greatly affect those water characteristics measured in the tank tests. It should be noted, however, that these pointed steps are merely alterations of a conventional step and the results should not prejudice conclusions regarding the effectiveness of other types of pointed steps.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 27, 1935.

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TABLE I

Offsets for N.A.C.A. Model No. 11-C Flying-Boat Hull (Inches)

		Distance from base line									Half breadths								
Station	Distance from F.P.	Keel	B1 [1]1.50	B2 3.00	B3 4.50	B4 6.00	B5 7.50	Main chine	Cove	Upper chine	Main chine	Cove	Upper chine	WL1 [2]12.50	WL2 11.00	WL3 9.50	WL4 8.00	WL5 6.50	Station
F.P.	0.0	4.00						4.00			0.15								F.P.
1/2	2.4	9.17	5.90					5.29			2.07						0.52	1.16	1/2
1	4.8	10.85	8.20	6.64				6.34			3.53					0.73	1.64	3.22	1
1-1/2	7.2	11.87	9.72	8.12	7.24			7.18			4.67				0.64	1.67	3.15		1-1/2
2	9.6	12.52	10.76	9.27	8.27			7.87			5.59			0.16	1.30	2.74	5.13		2
3	14.4	13.21	12.01	10.83	9.83	9.13		8.89			6.90			.93	2.76	5.10			3
4	19.2	13.47	12.62	11.72	10.91	10.18	9.62	9.56			7.71								4
5	24.0	13.58	12.94	12.23	11.53	10.85	10.22	9.97			8.17								5
6	28.8	13.66	Elements of stations Straight lines from here aft					10.19			8.40								6
7	33.6	13.75						10.30			8.49								7
8	38.4	13.83						10.38			8.50								8
9	43.2	13.92						10.47			8.50								9
10,F.	48.0	14.00						10.55			8.50								10,F.
10,A.	48.0	13.44						9.98			8.50								10,A.
11	52.8	12.97						9.51			8.50								11
12	57.6	12.51						9.22	8.29	8.16	8.10	8.10	8.40						12
13	62.4	12.04						9.22	7.63	7.15	6.97	6.97	8.11						13
14	67.2	11.58						9.54	7.27	6.23	5.07	5.07	7.58						14
15	72.0	11.11						10.10	7.17	5.44	2.59	2.59	6.77						15
S.P.	76.0	10.74 7.24						10.72	7.22		.20	.20							S.P.
16	76.8	7.04								4.71			5.78						16
17	81.6	5.91								4.06			4.61						17
18	86.4	4.77								3.46			3.31						18
19	91.2	3.64								2.91			1.90						19
20	96.0	2.50								2.39			.40						20

[1]Distance from center line (plane of symmetry) to buttock (section of hull surface made by a vertical plane parallel to plane of symmetry)

[2]Distance from base line to water line (section of hull surface made by a horizontal plane parallel to base line)

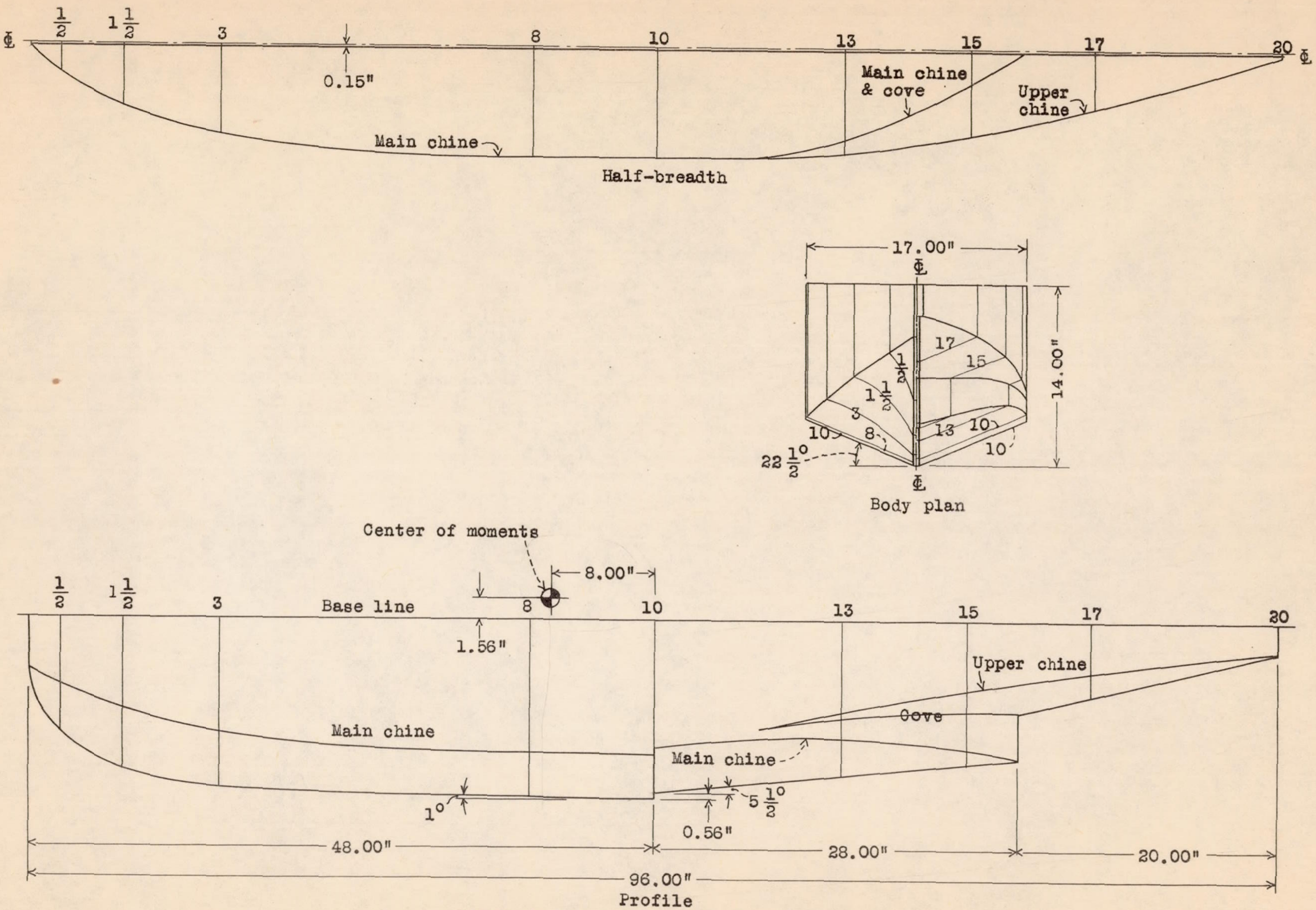


Figure 1.-Lines of N.A.C.A. model 11-C.

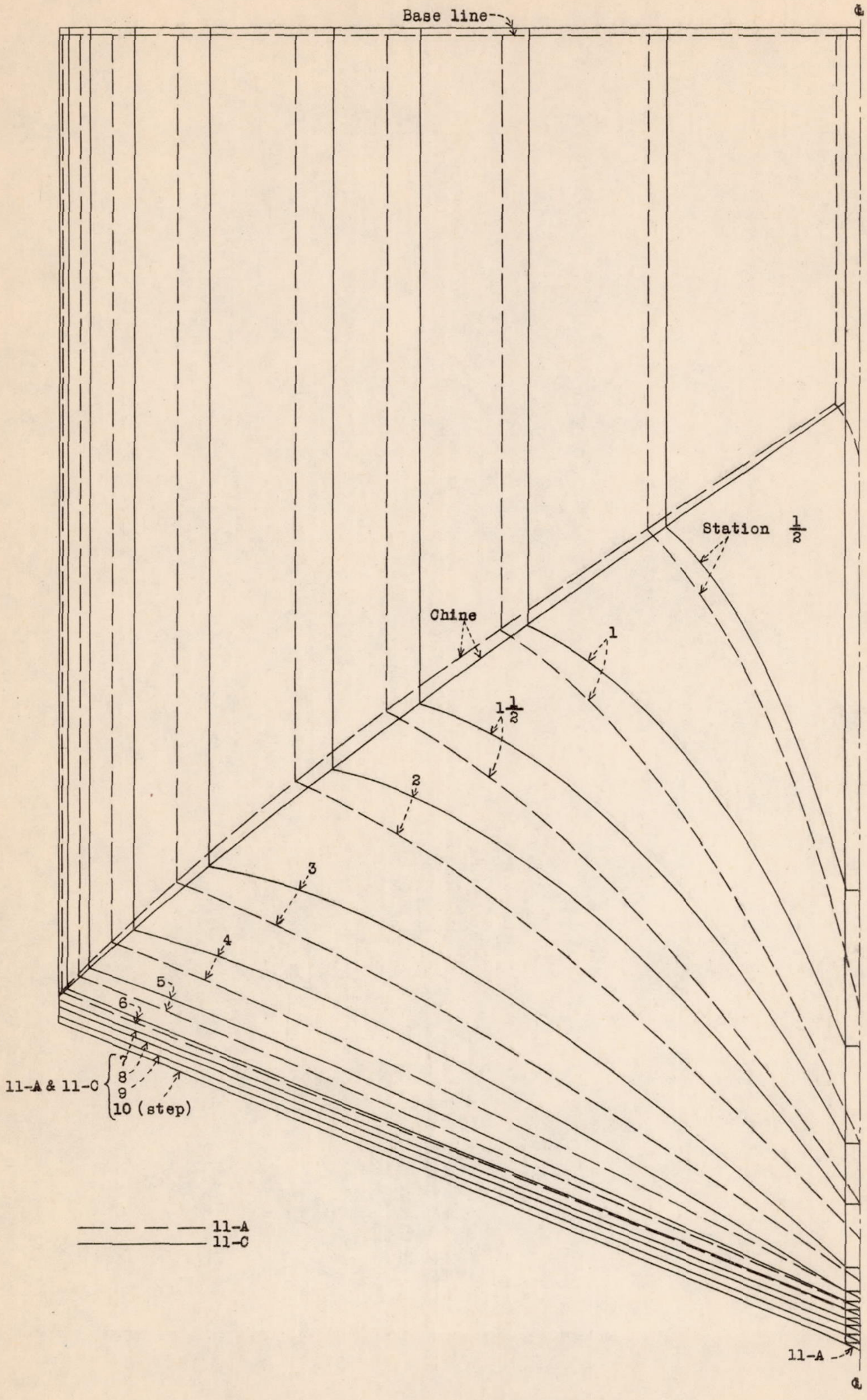


Figure 2.- Comparison of forebodies of models 11-C and 11-A

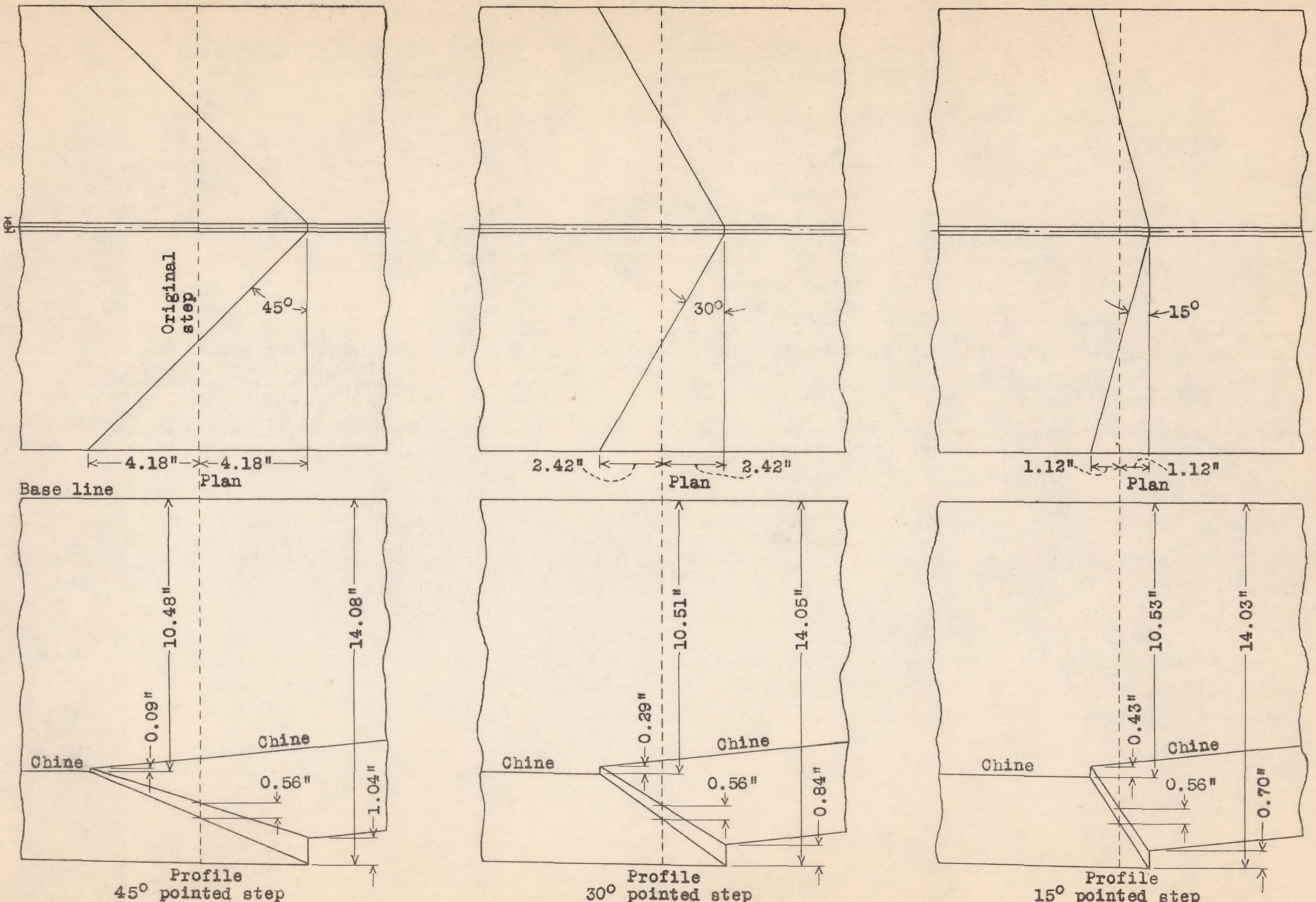


Figure 3.-Model 11-C, pointed steps.

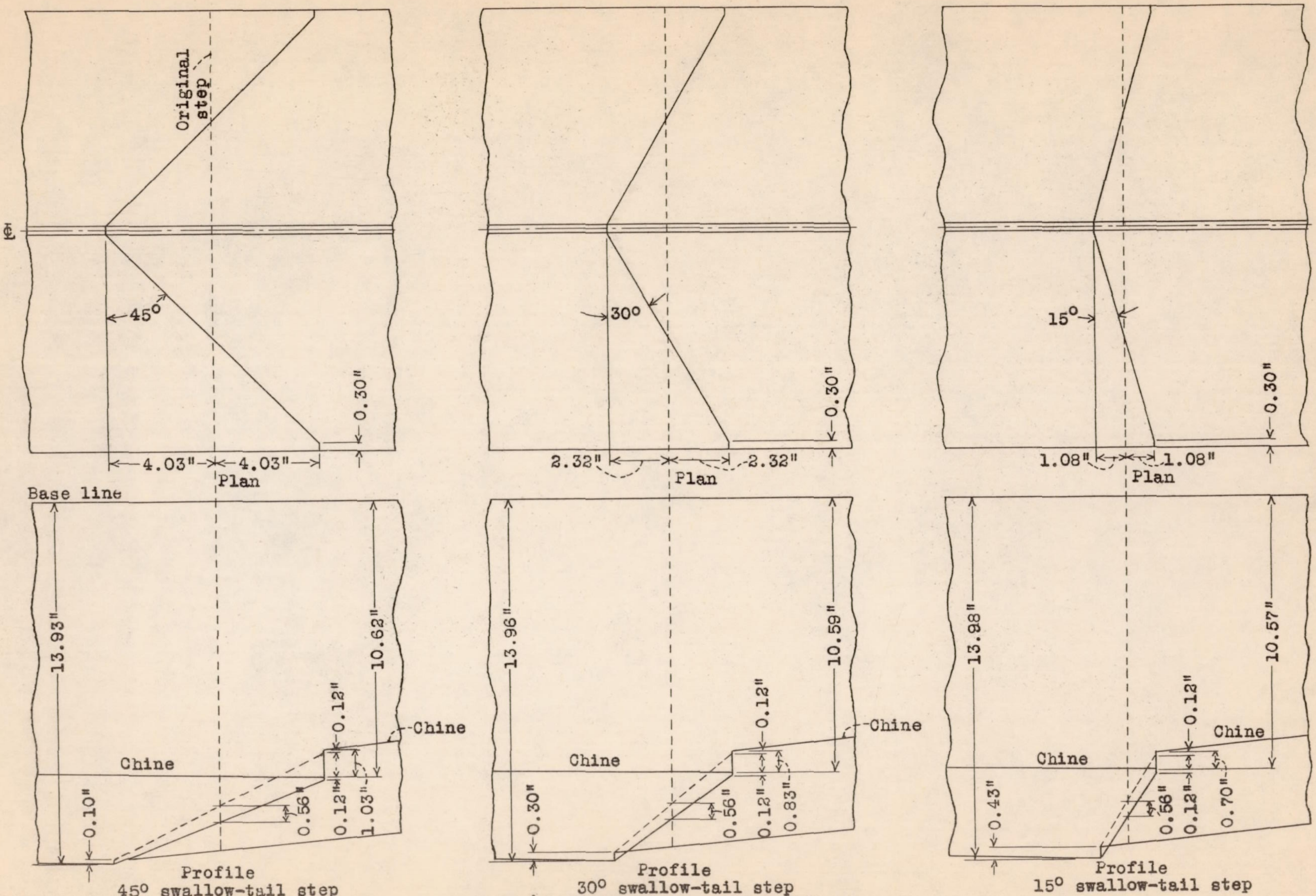


Figure 4.-Model 11-C, swallow-tail steps.

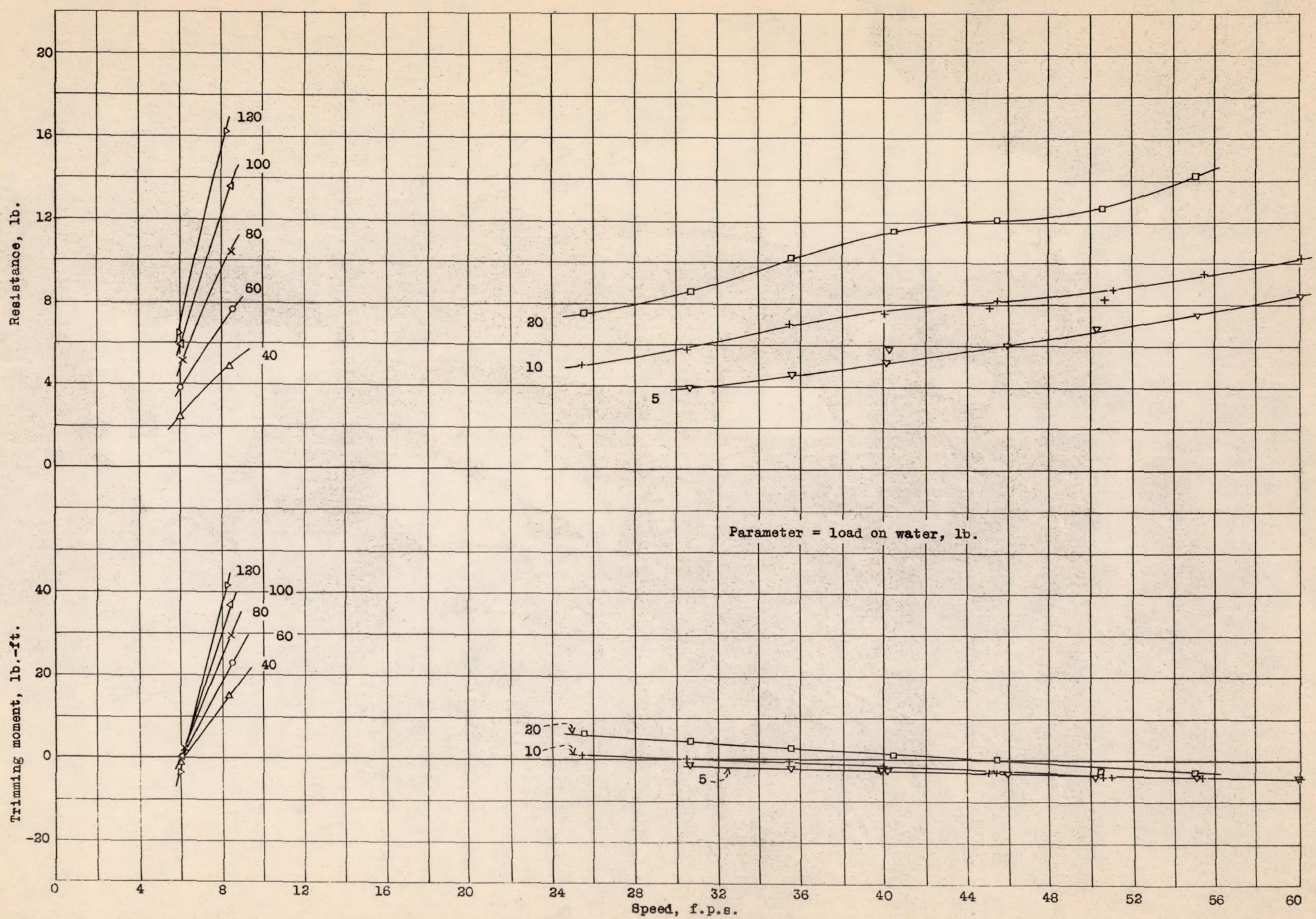


Figure 5.- Resistance and trimming moment for model 11-C, $\tau = 2°$

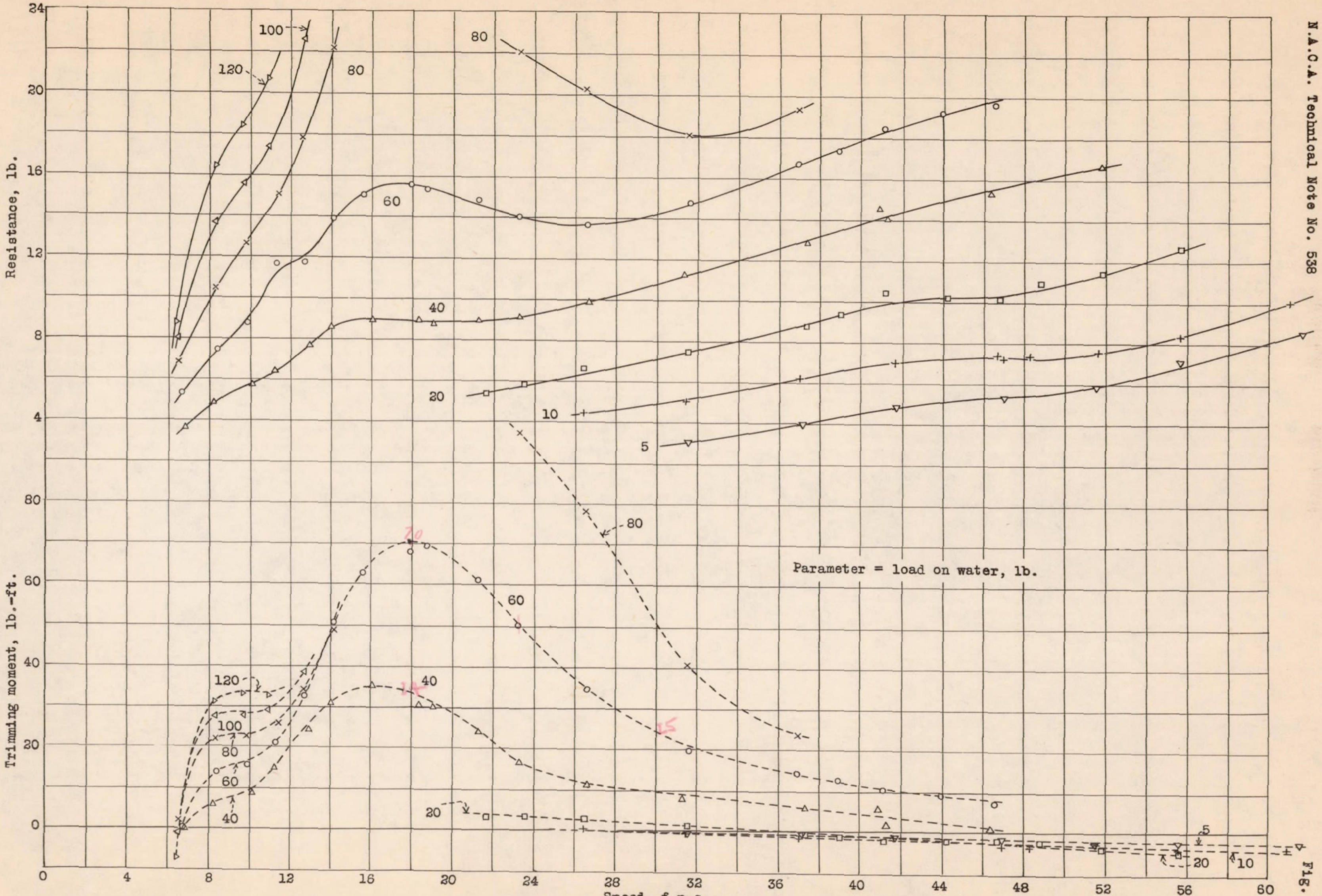


Figure 6.- Resistance and trimming moment for model 11-C, $\tau = 3^{\circ}$

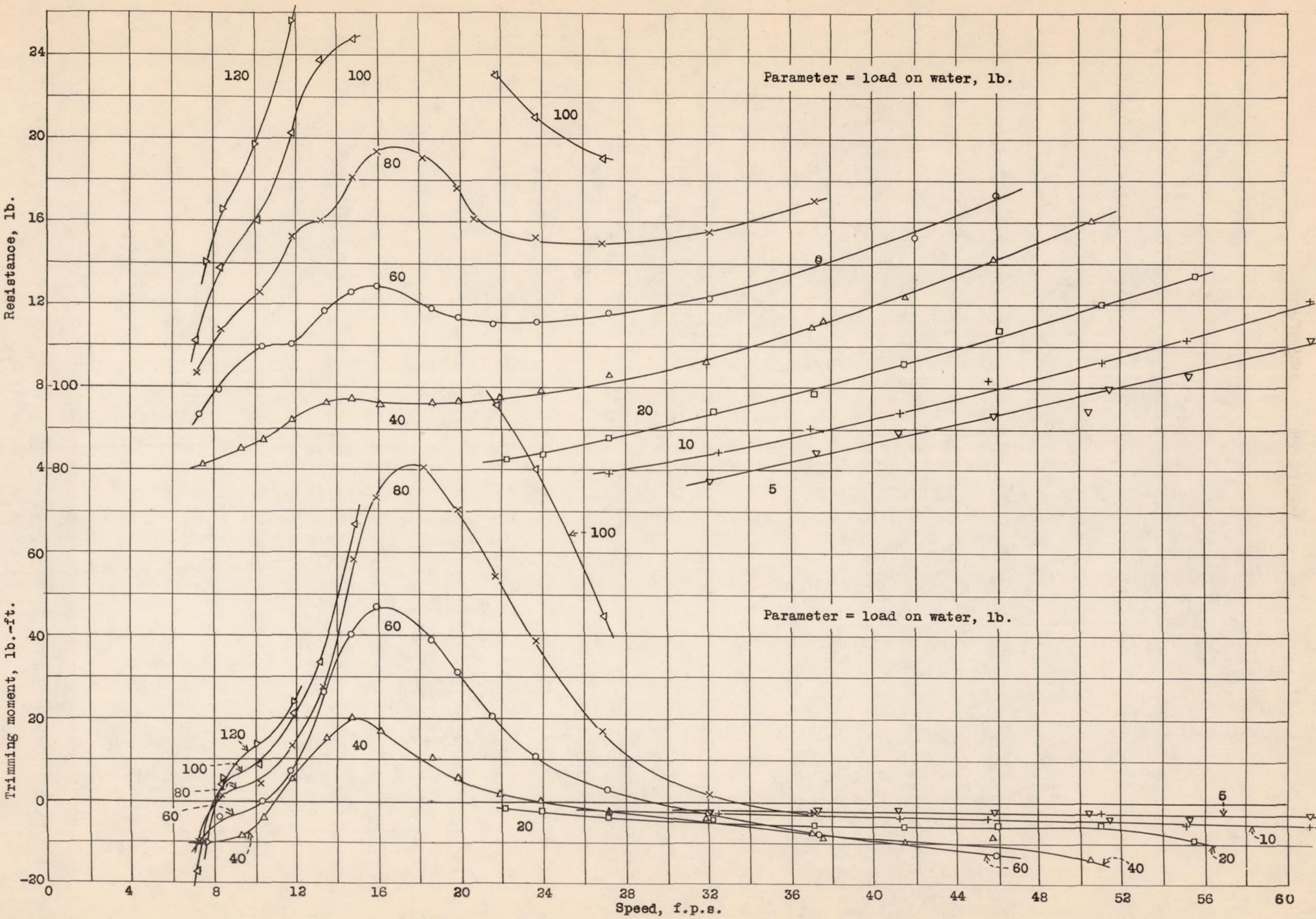


Figure 7.- Resistance and trimming moment for, model 11-C, $\tau = 5^{\circ}$

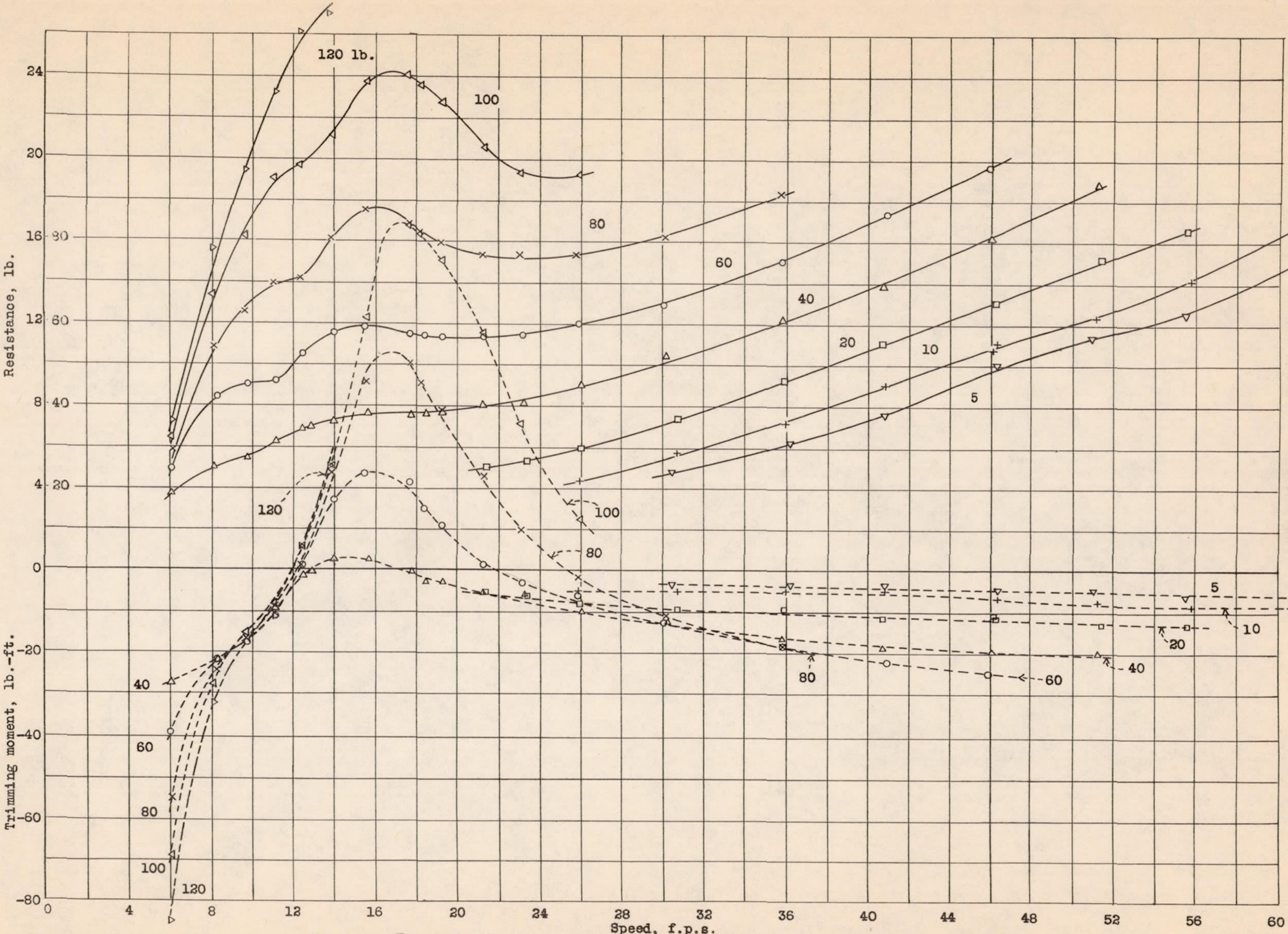


Figure 8.- Resistance and trimming moment for model 11-C, $\tau = 7^{0}$

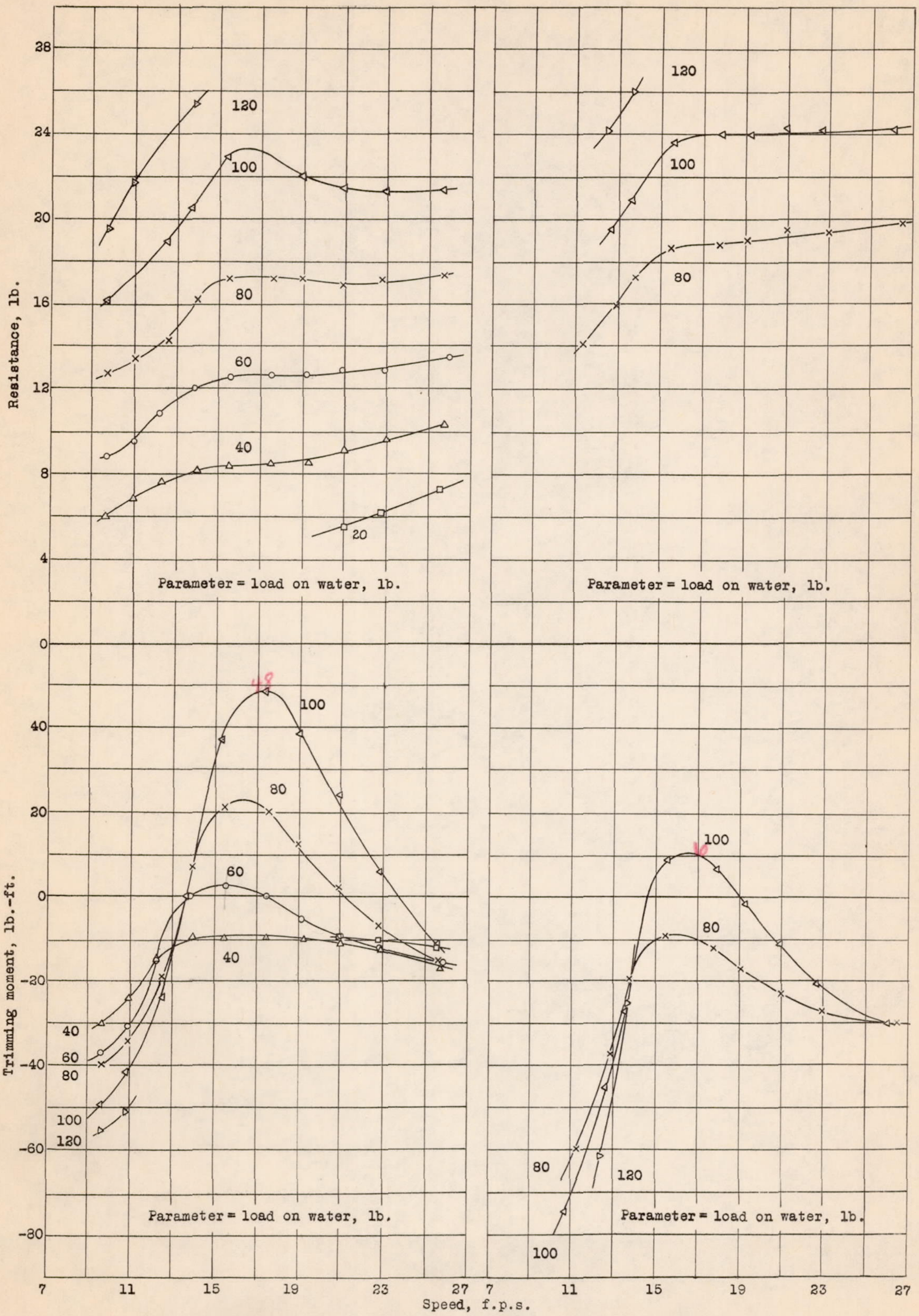


Figure 9.- Resistance and trimming moment for model 11-C, $\tau = 9^{\circ}$

Figure 10.- Resistance and trimming moment for model 11-C, $\tau = 11^{\circ}$

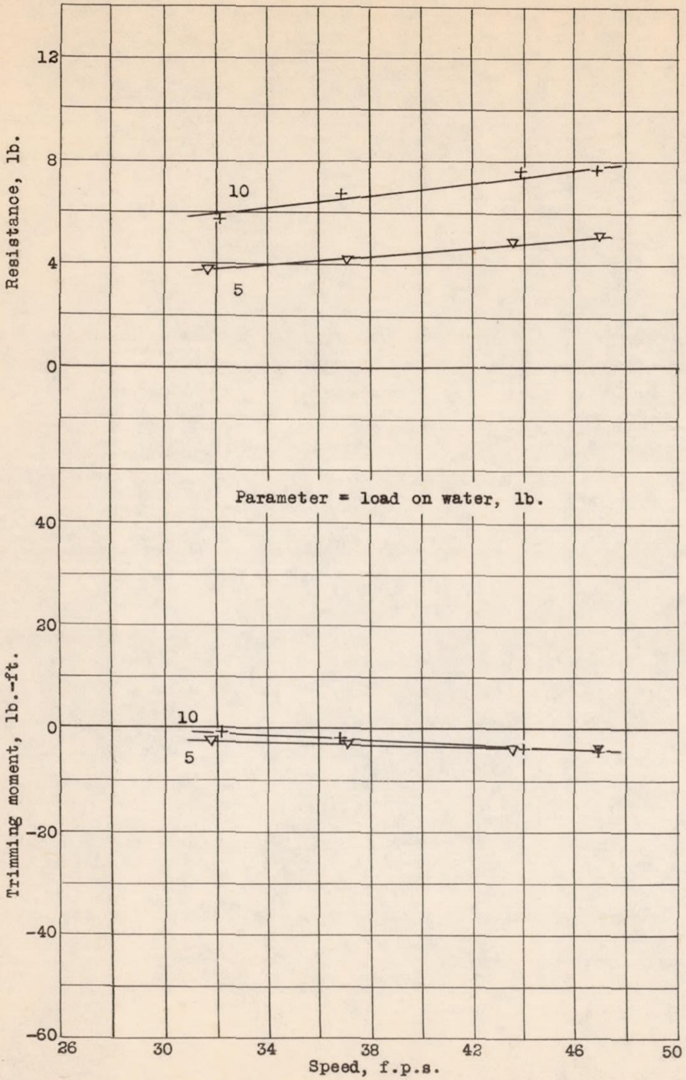


Figure 11.- Resistance and trimming moment for model 11-C with 45° pointed step, $\tau = 2°$.

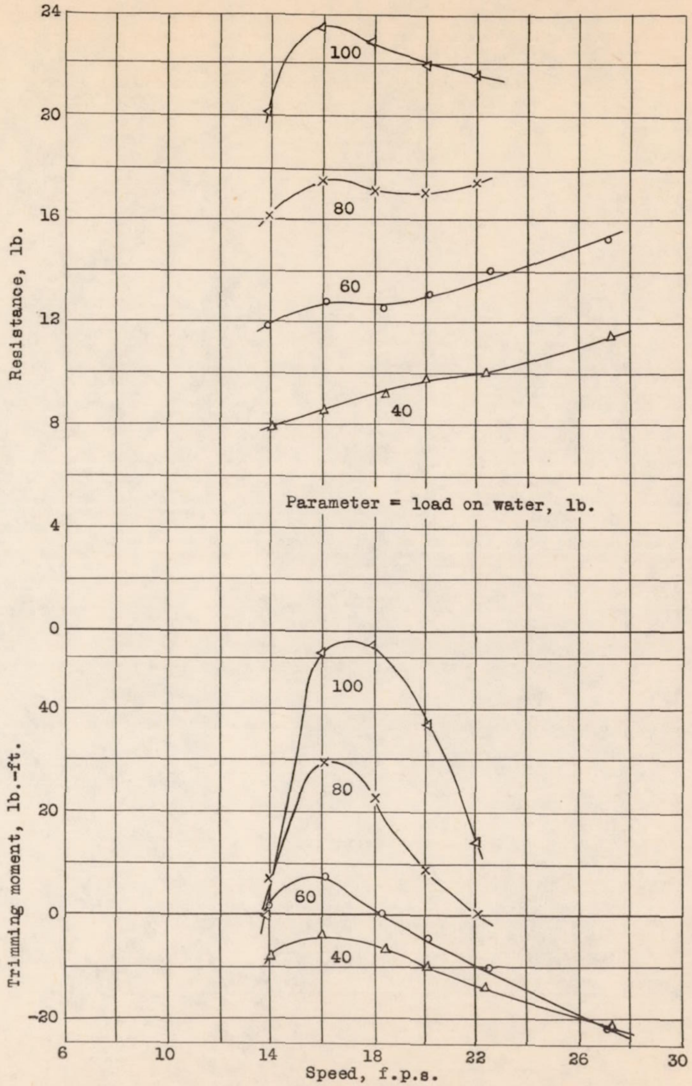


Figure 15.- Resistance and trimming moment for model 11-C with 45° pointed step, $\tau = 9°$.

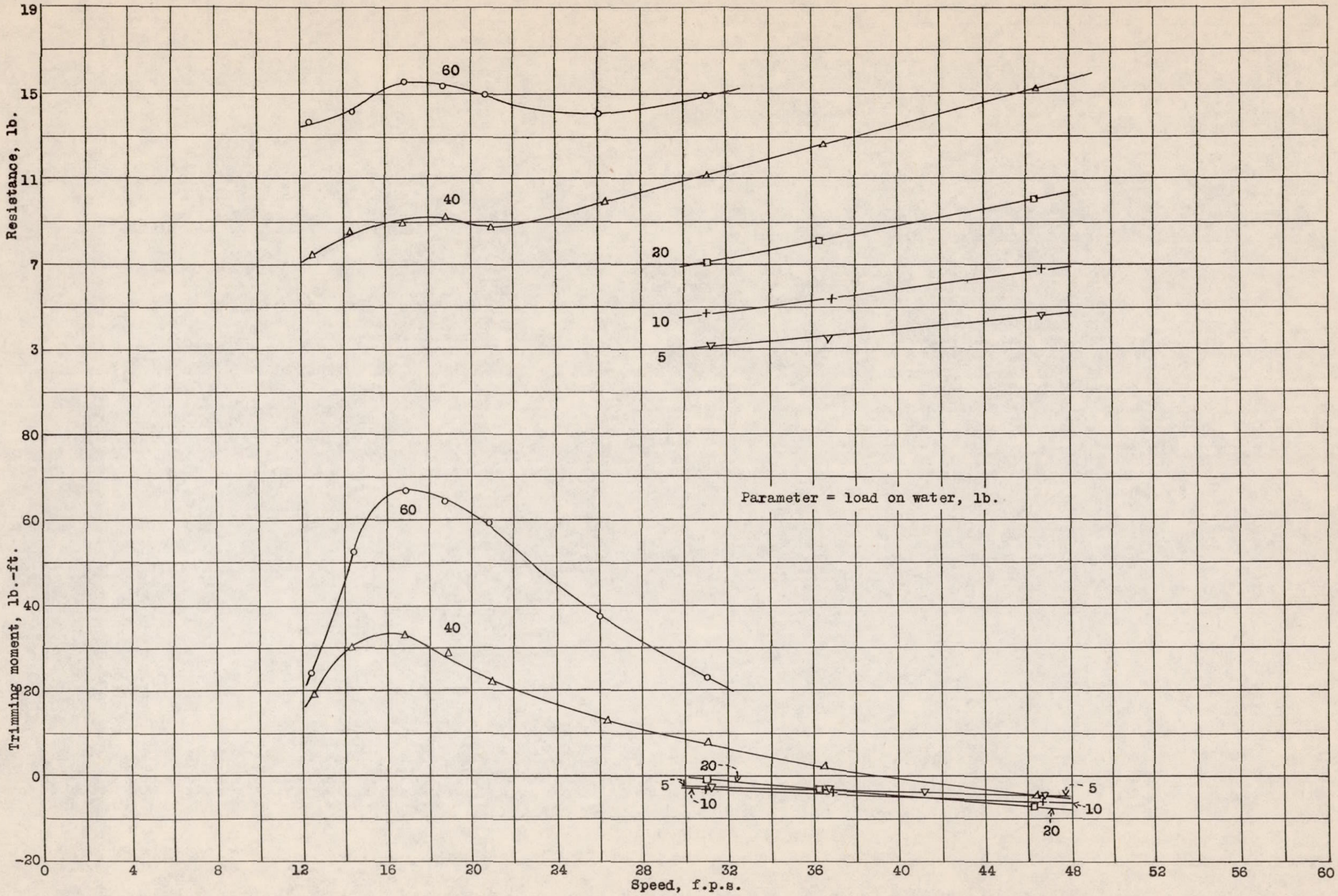


Figure 12.- Resistance and trimming moment for model 11-C with 45° pointed step, $\tau = 3°$.

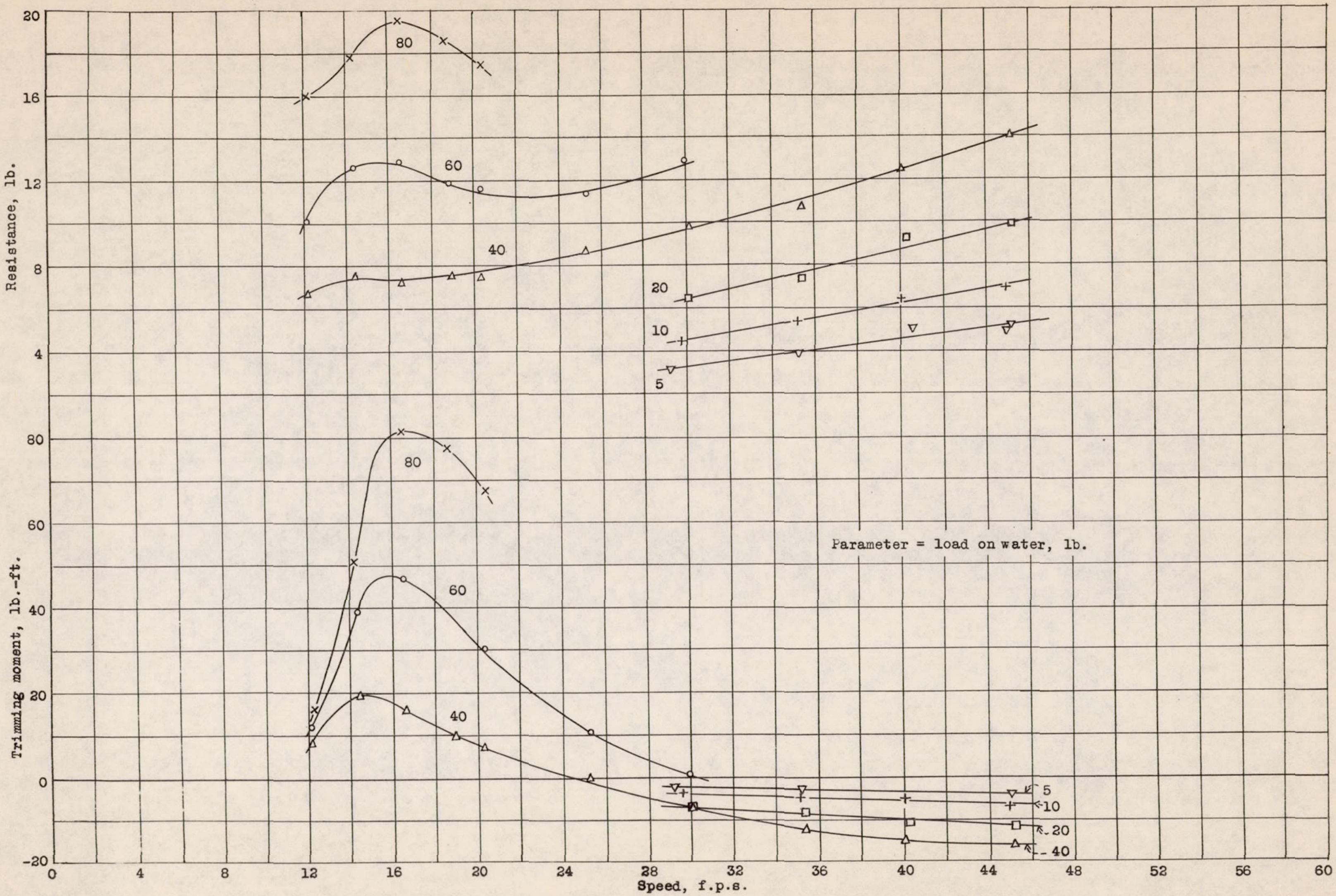


Figure 13.- Resistance and trimming moment for model 11-C with 45° pointed step, $\tau = 5°$.

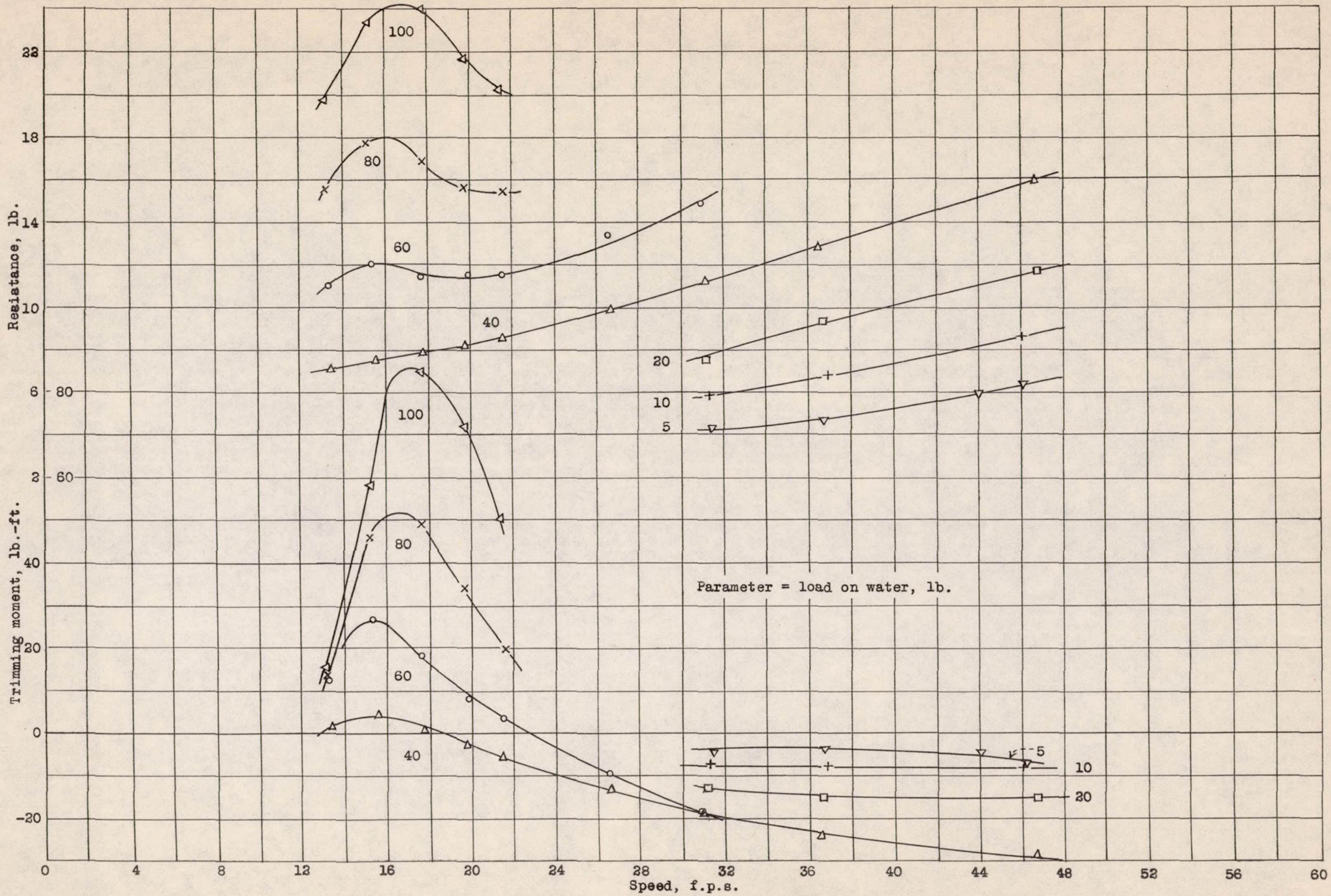


Figure 14.- Resistance and trimming moment for model 11-C with 45° pointed step, τ = 7°.

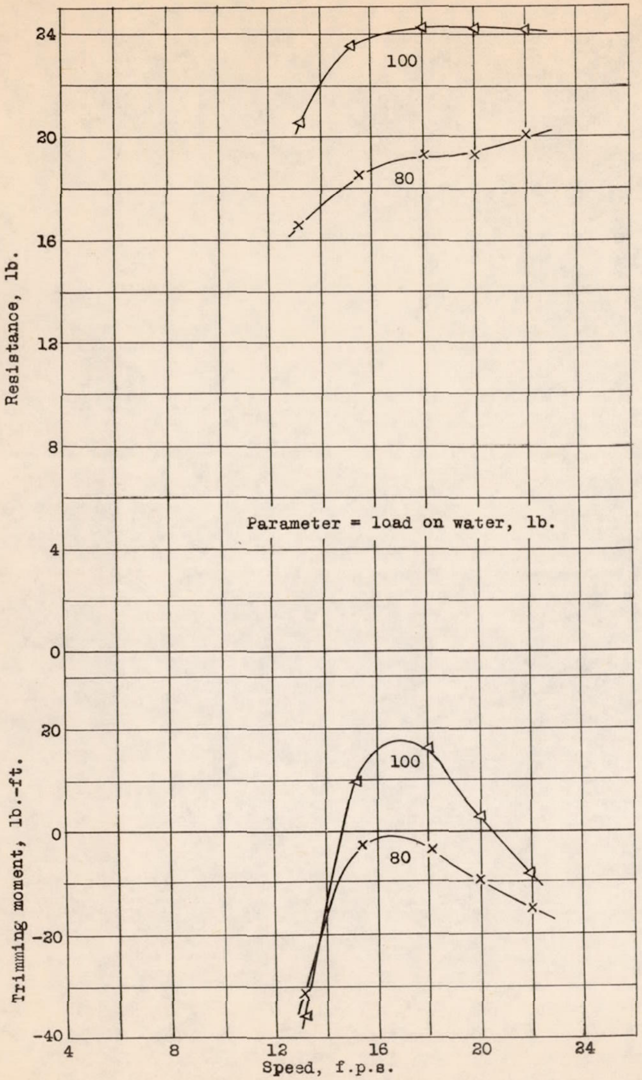


Figure 16.- Resistance and trimming moment for model 11-C with 45° pointed step, $\tau = 11°$.

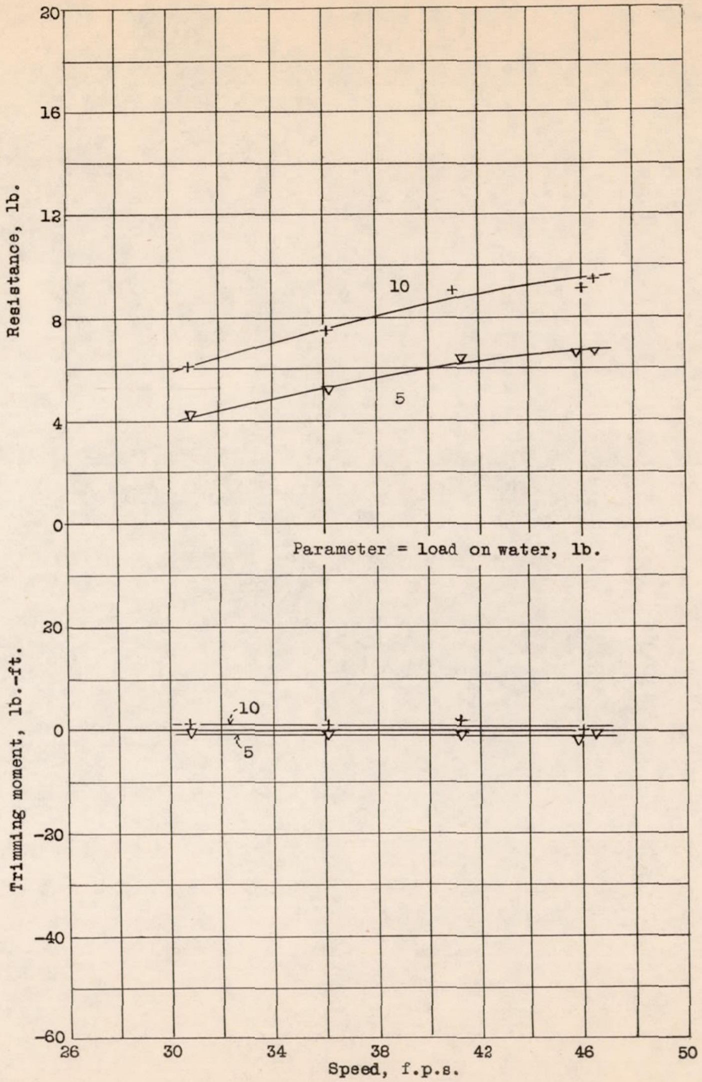


Figure 17.- Resistance and trimming moment for model 11-C with 30° swallow-tail step, $\tau = 2°$.

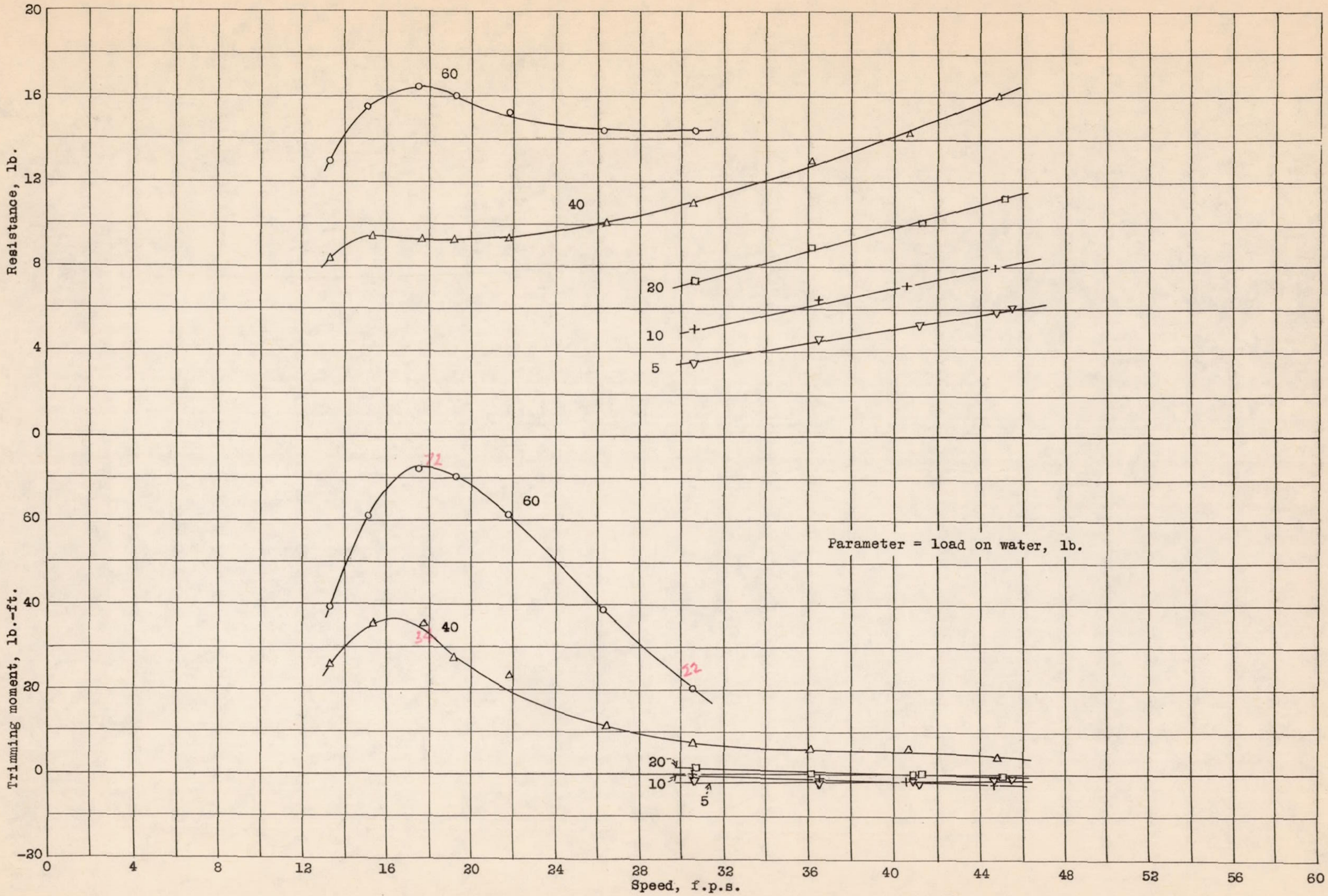


Figure 18.- Resistance and trimming moment for model 11-C with 30° swallow-tail step, $\tau = 3°$

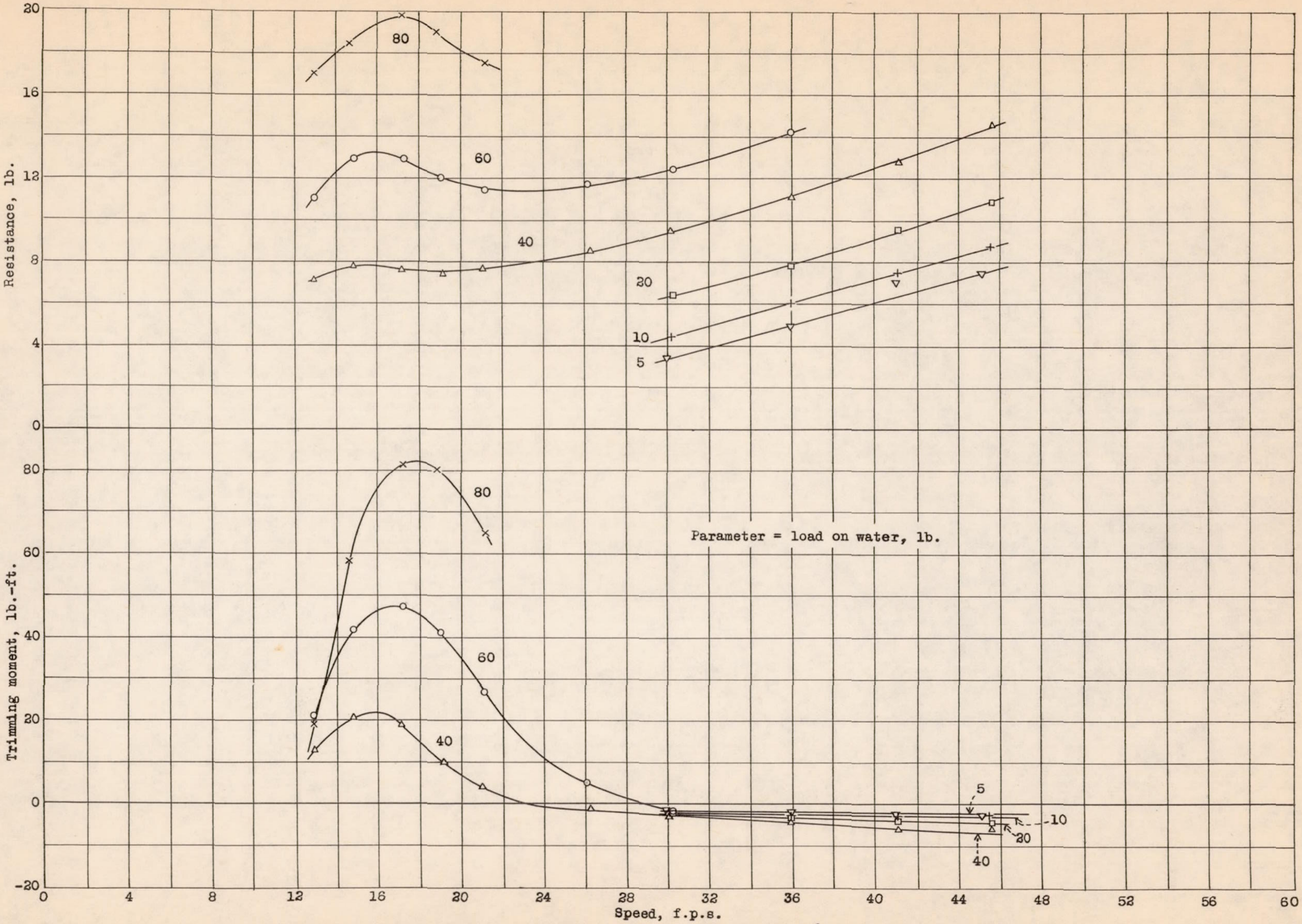


Figure 19.- Resistance and trimming moment for model 11-C with 30° swallow-tail step, $\tau = 5°$

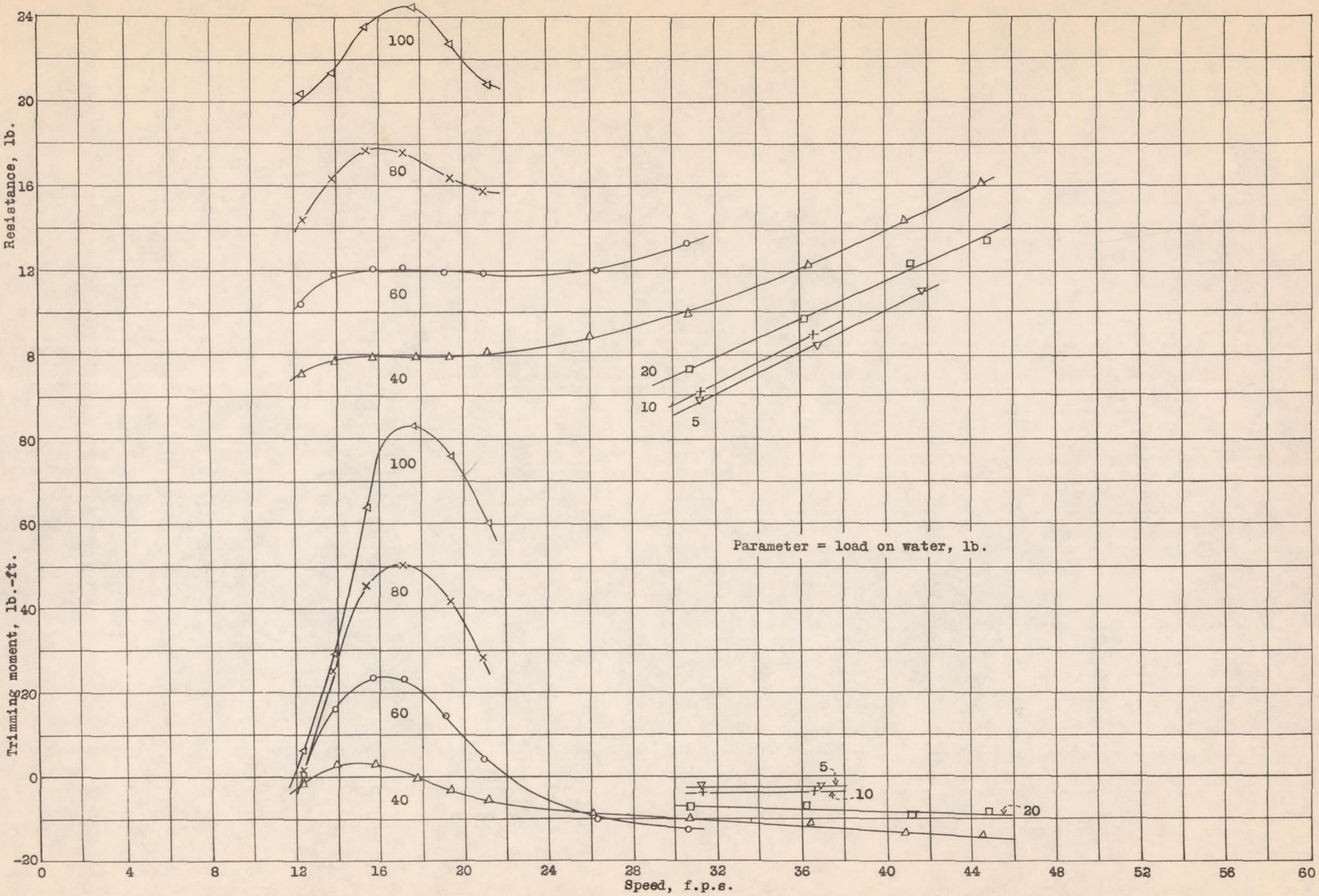


Figure 20.- Resistance and trimming moment for model 11-C with 30° swallow-tail step, $\tau = 7^{\circ}$

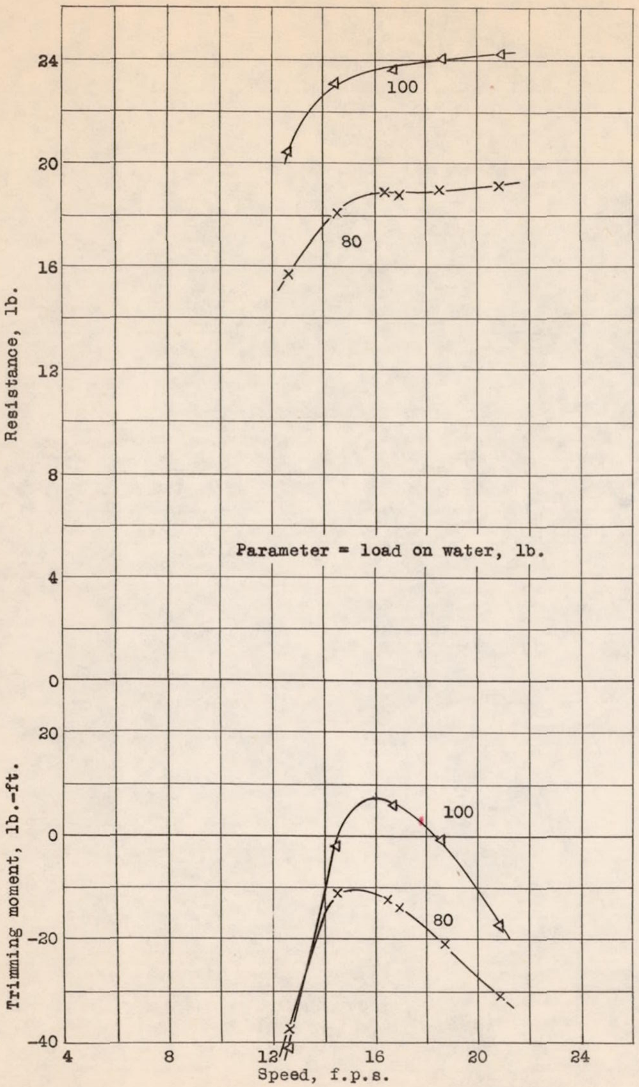


Figure 22.- Resistance and trimming moment for model 11-C with 30° swallow-tail step, τ = 11°.

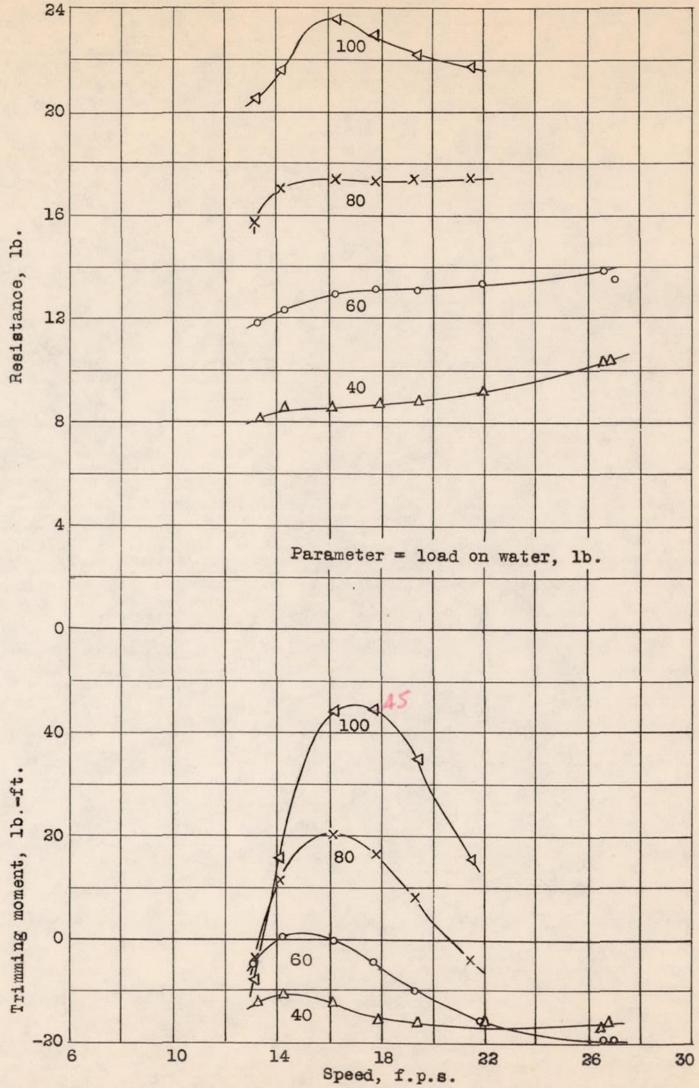


Figure 21.- Resistance and trimming moment for model 11-C with 30° swallow-tail step, τ = 9°.

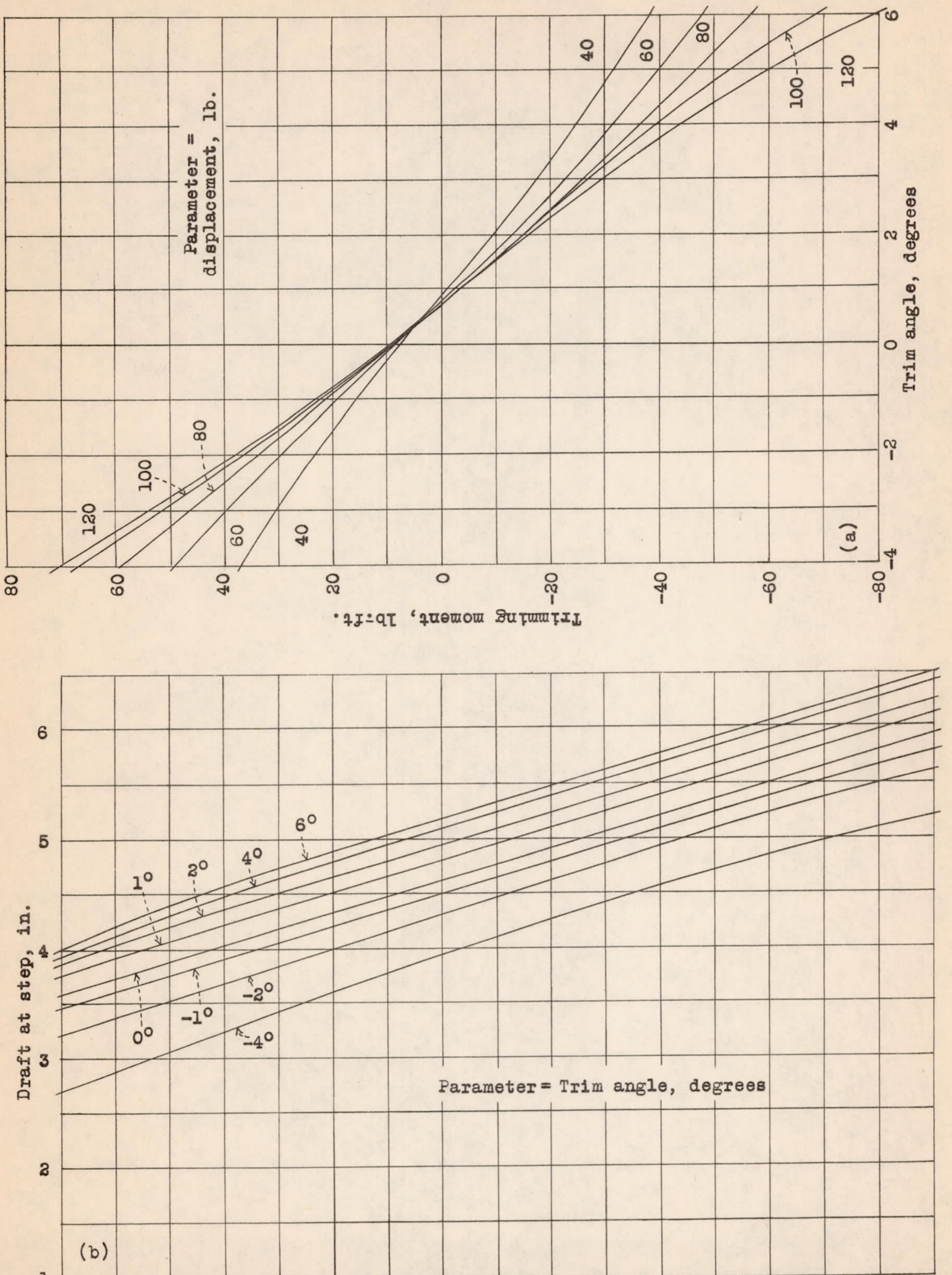


Figure 23a,b.- Static trimming moments and drafts, model 11-C.

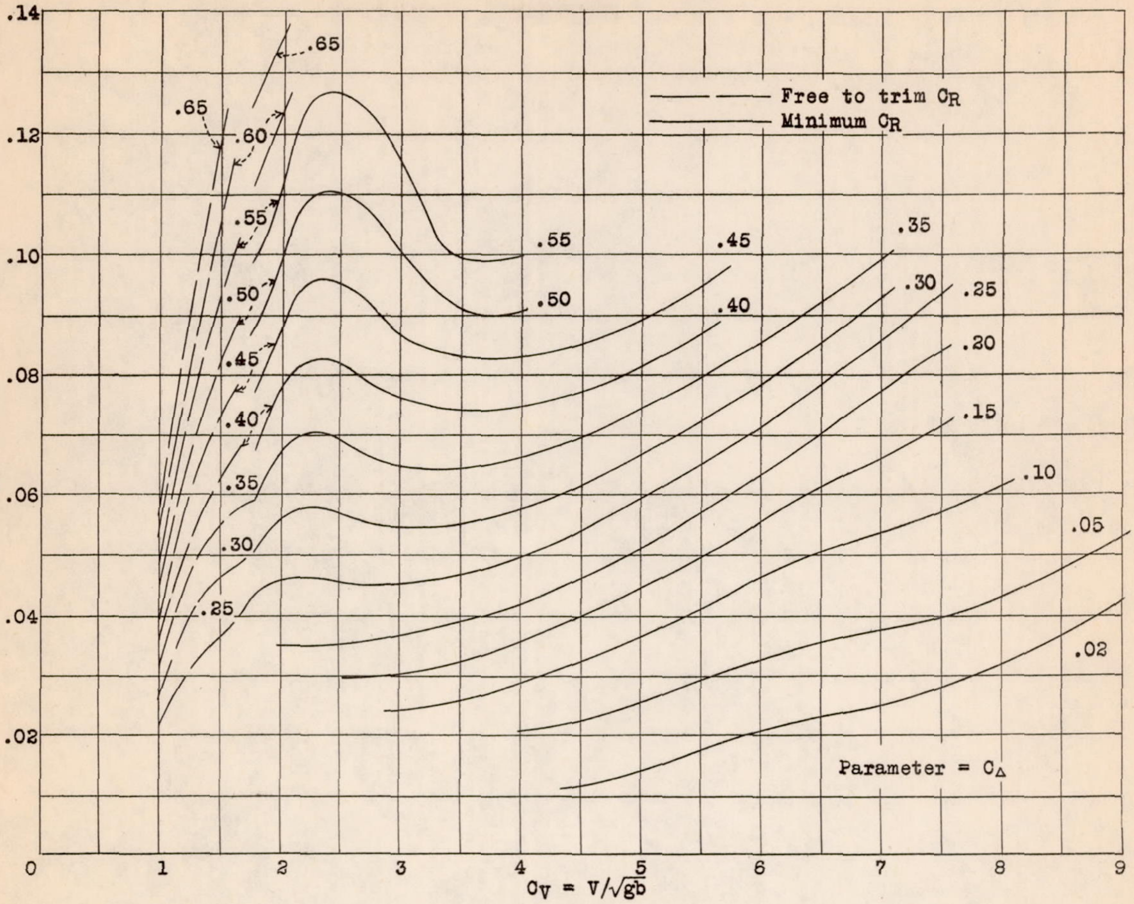


Figure 24.- Variation of C_R with C_V, model 11-C.

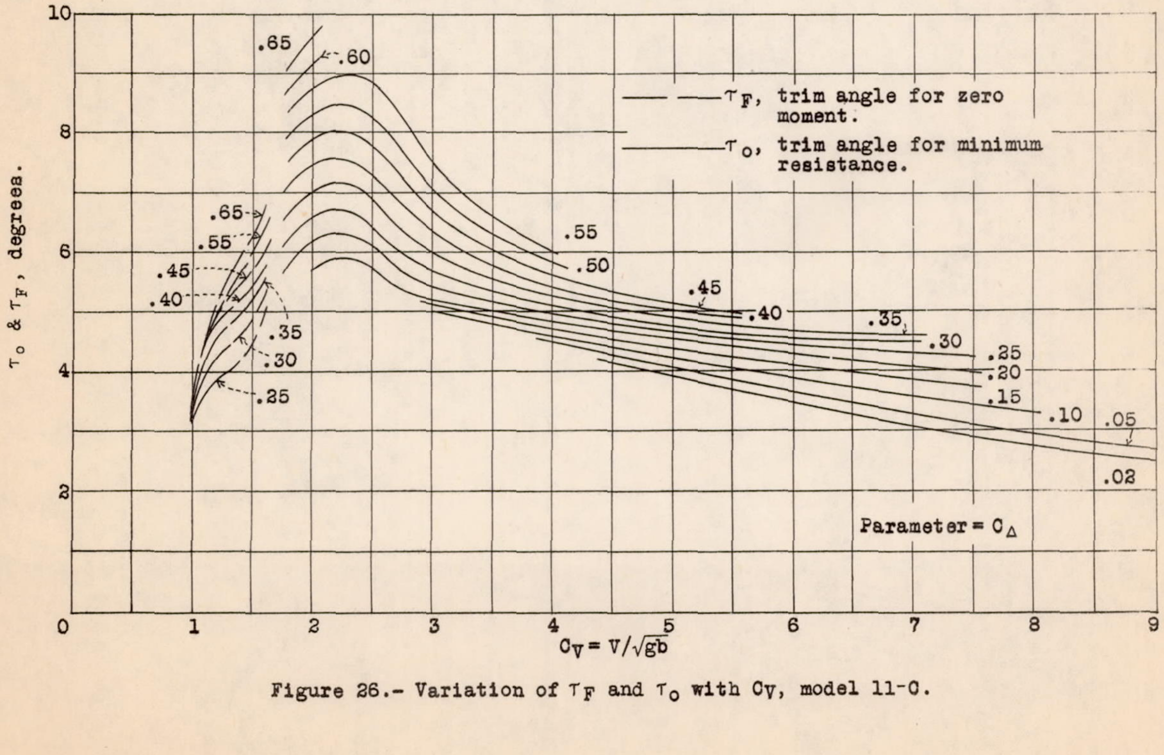


Figure 26.- Variation of τ_F and τ_o with C_V, model 11-C.

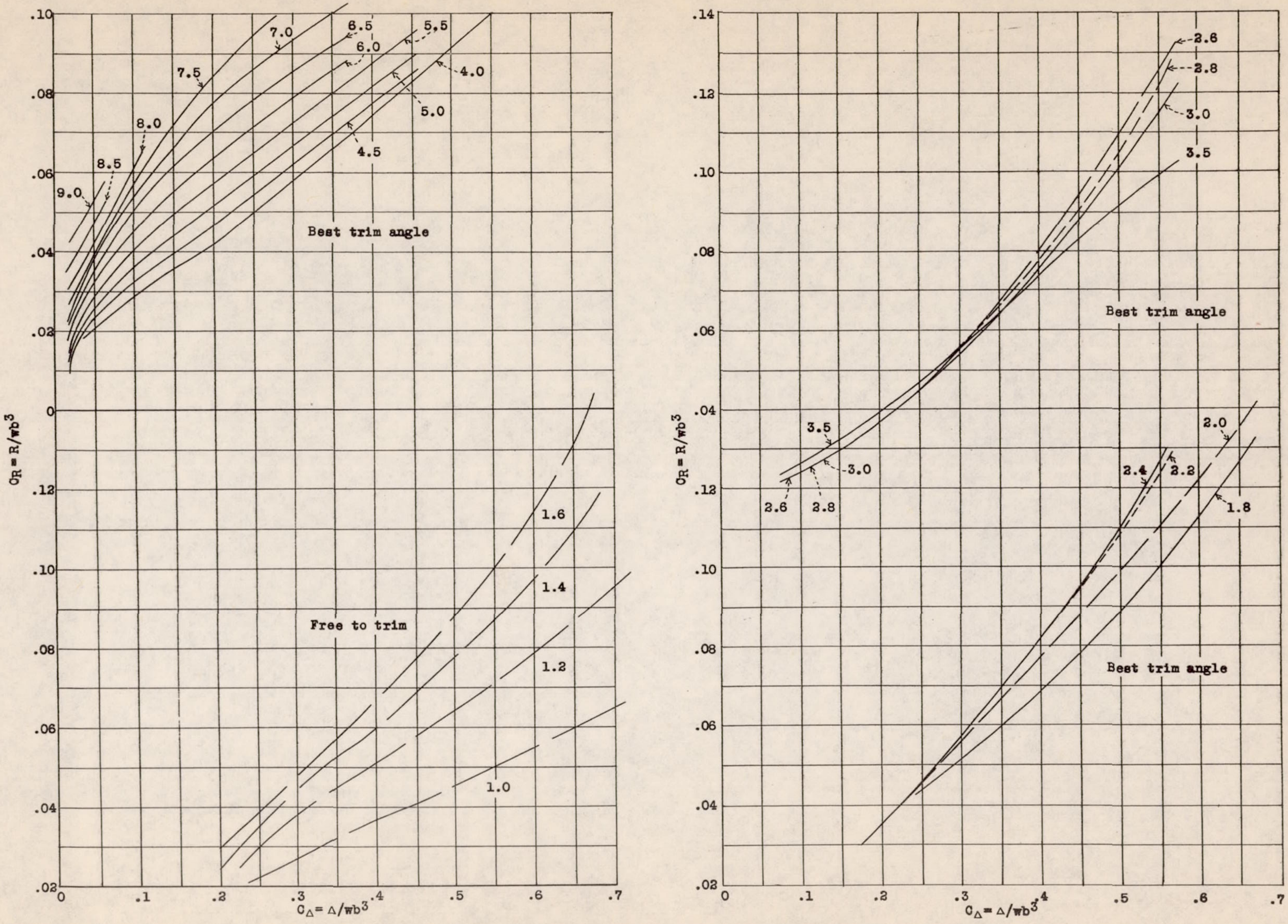


Figure 25.- Variation of C_R with C_Δ, model 11-C.

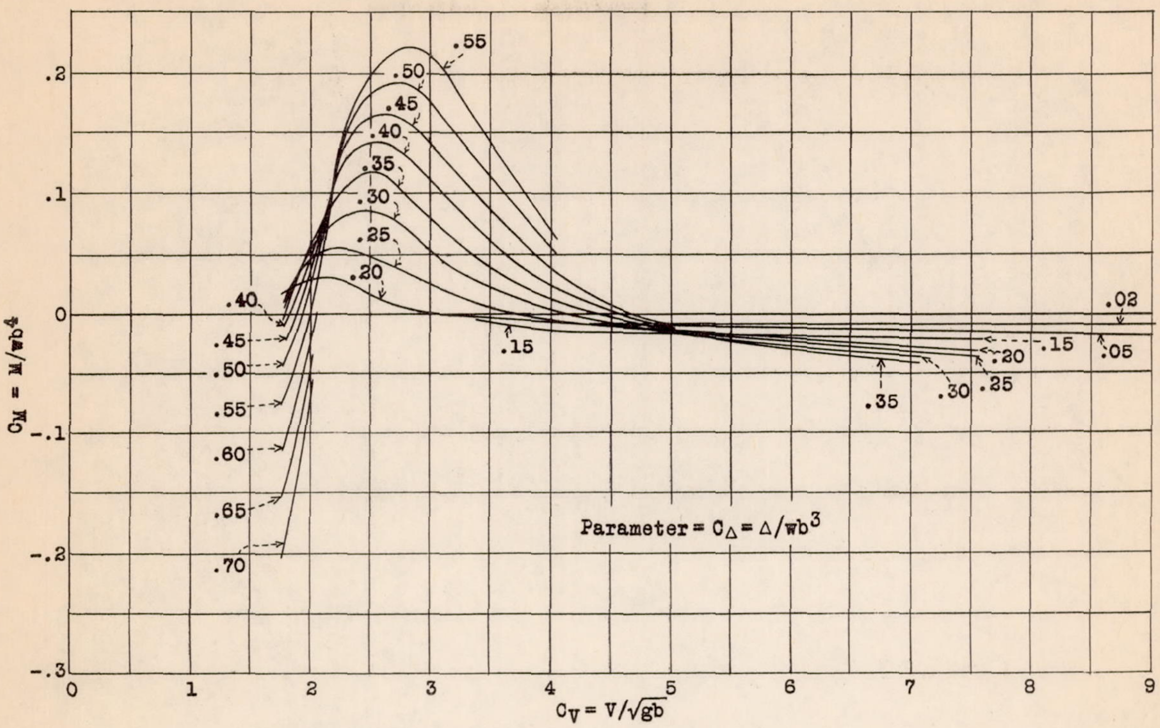


Figure 27.- Variation of C_M with C_V, model 11-C.

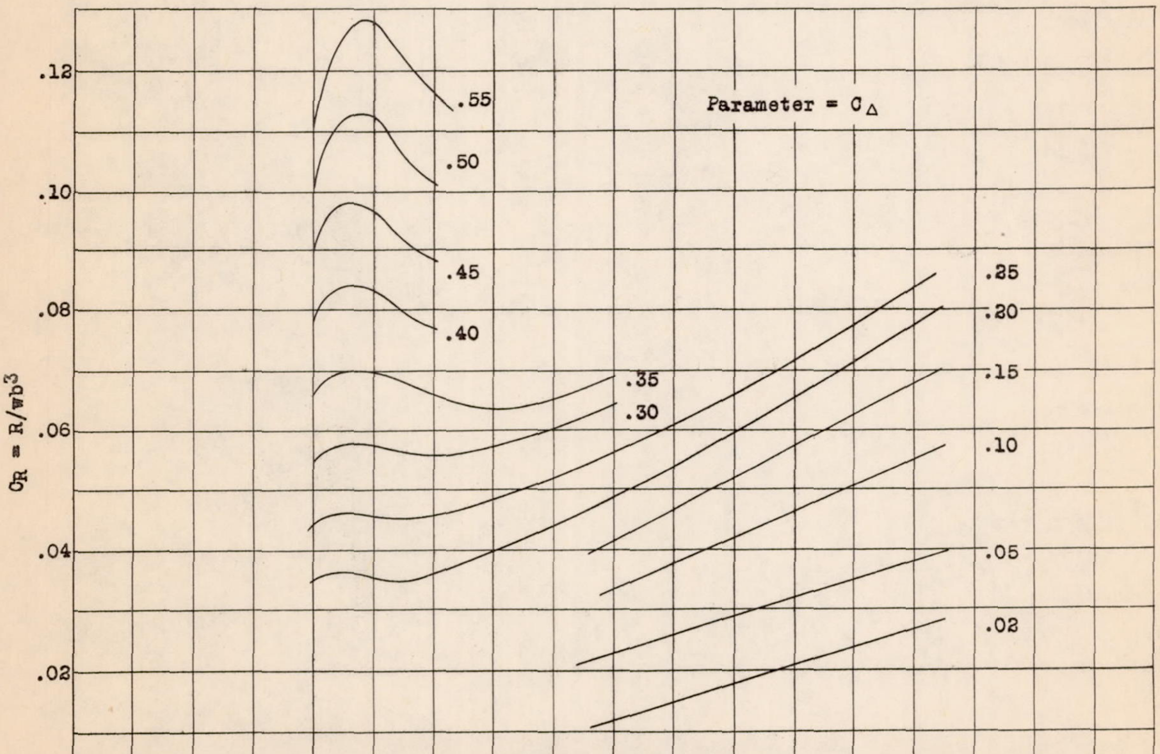
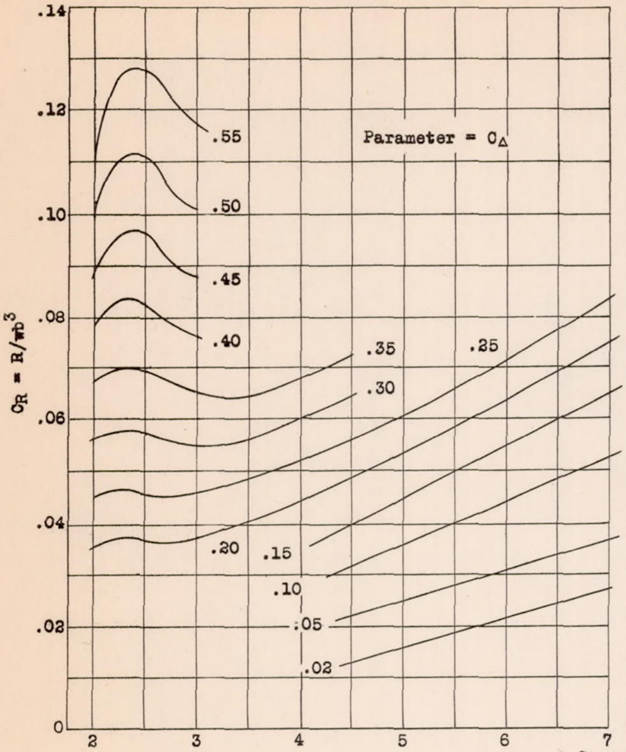


Figure 28.- Variation of C_R with C_V, model 11-C with 15° pointed step.



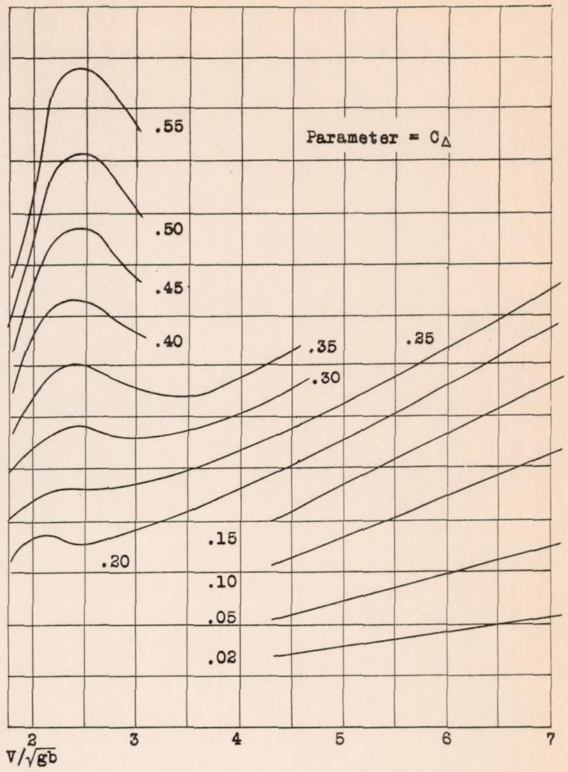
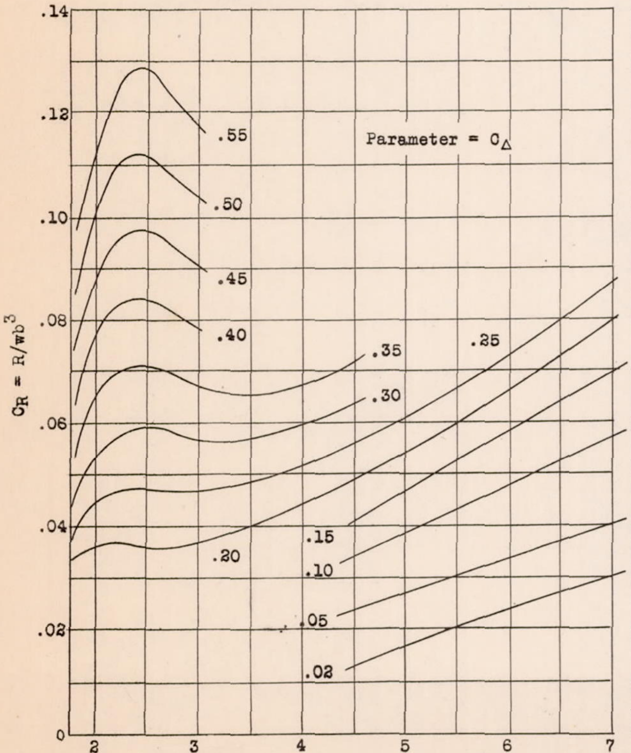


Figure 29.- Variation of C_R with C_V, model 11-C with 30° pointed step.

Figure 30.- Variation of C_R with C_V, model 11-C with 45° pointed step.



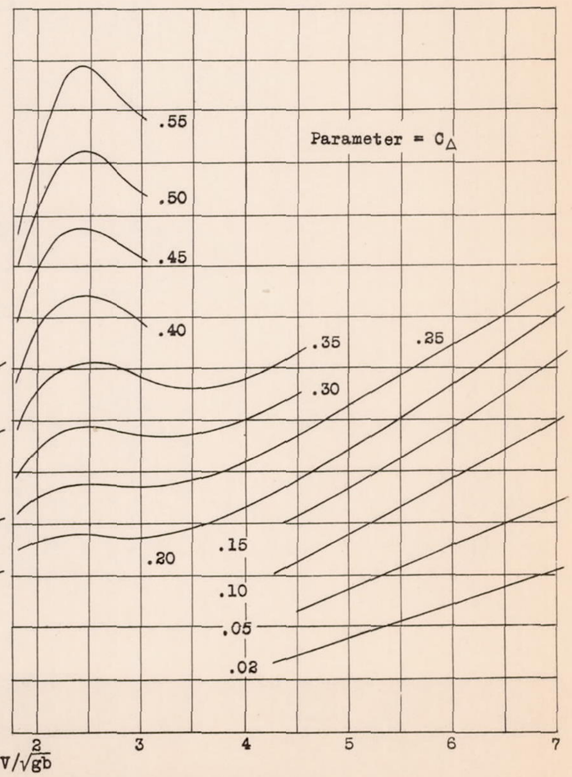


Figure 31.- Variation of C_R with C_V, model 11-C with 15° swallow-tail step.

Figure 32.- Variation of C_R with C_V, model 11-C with 30° swallow-tail step.

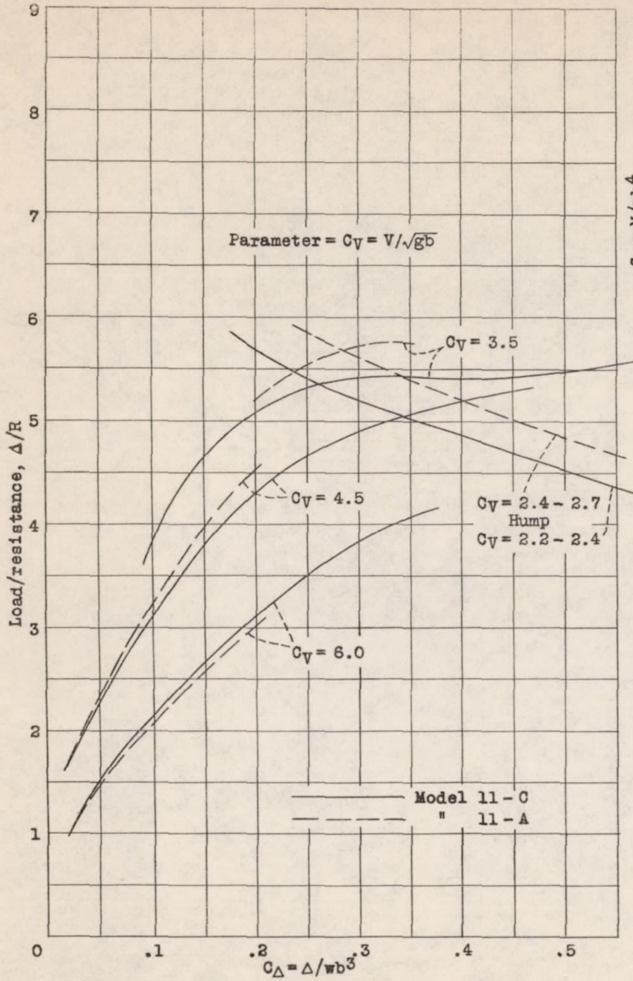


Figure 33.- Comparison of Δ/R values for models 11-C and 11-A.

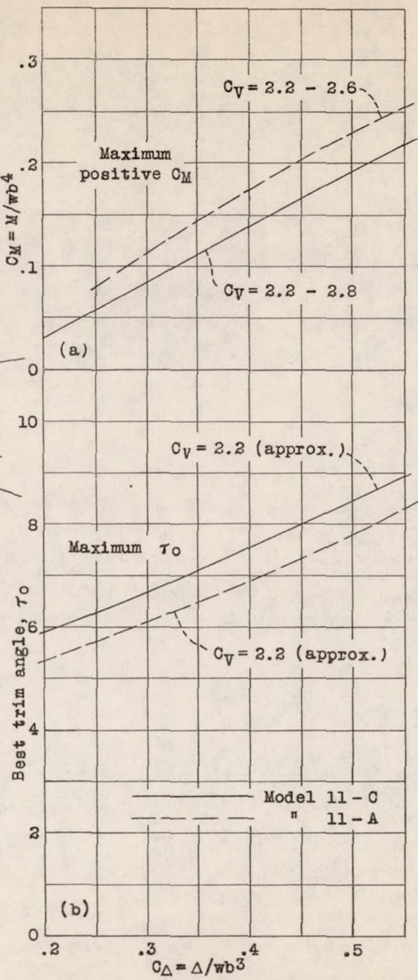


Figure 34.- Comparison of *maximum* trimming-moment coefficient and maximum best trim angle for models 11-C and 11-A.

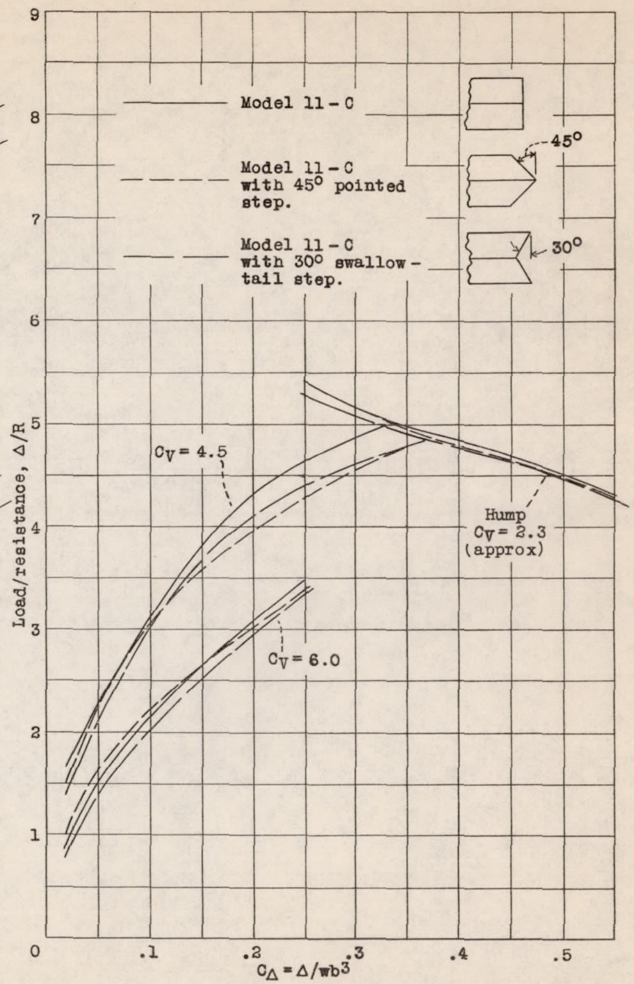
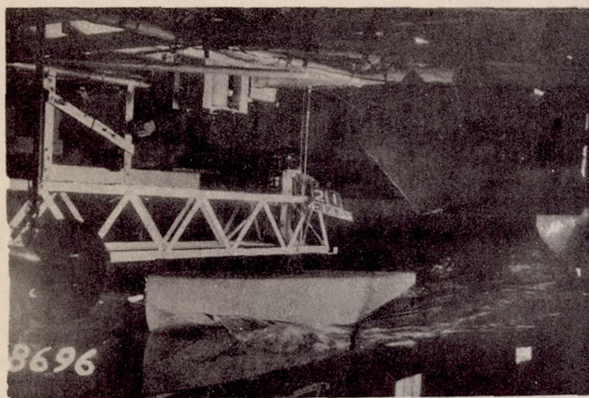
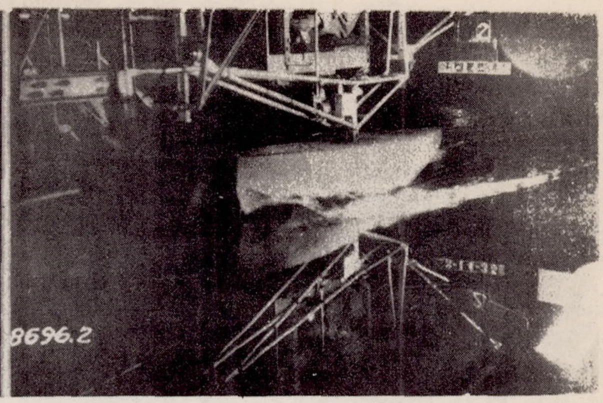


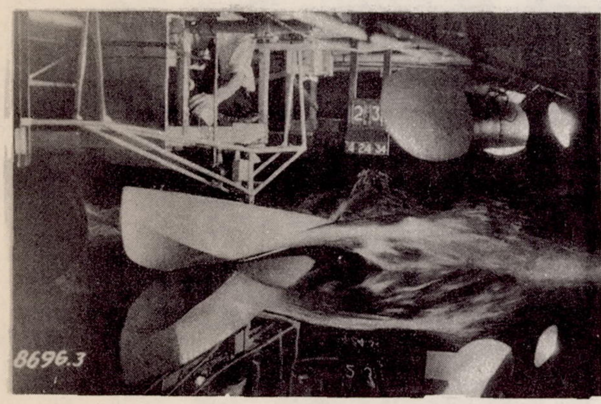
Figure 35.- Effect of pointed and swallow-tail steps on values of Δ/R.



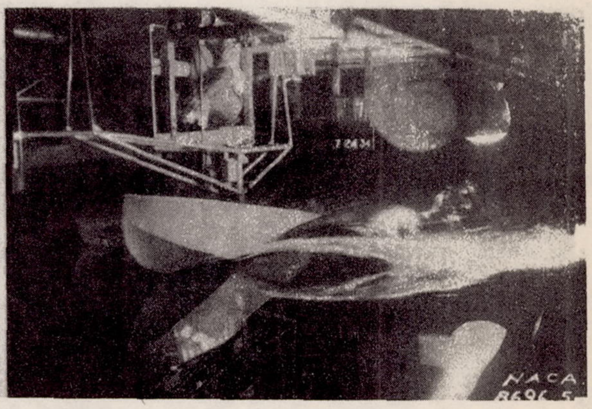
6.8 f.p.s., $\tau=3^{\circ}$, $\Delta=100$ lb.



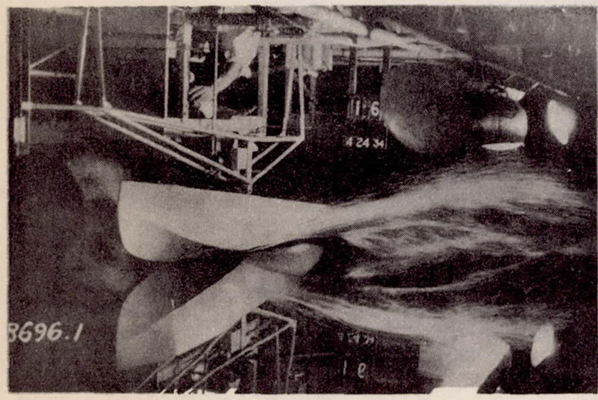
6.6 f.p.s., $\tau=3^{\circ}$, $\Delta=100$ lb.



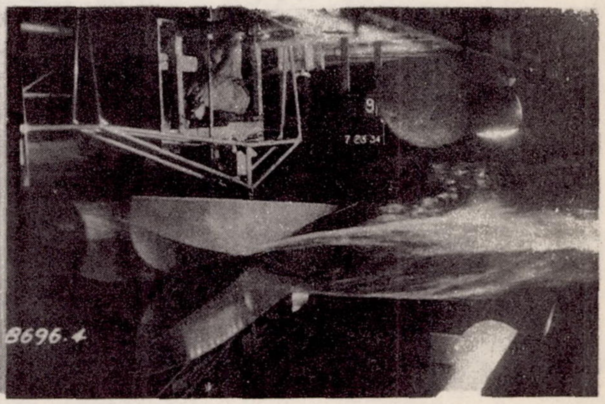
14.7 f.p.s., $\tau=9^{\circ}$, $\Delta=100$ lb.



15.3 f.p.s., $\tau=9^{\circ}$, $\Delta=100$ lb.



20.0 f.p.s., $\tau=7^{\circ}$, $\Delta=100$ lb.



19.2 f.p.s., $\tau=7^{\circ}$, $\Delta=100$ lb.

Model 11-A

Model 11-C

Figure 36.-Spray photographs of models 11-A and 11-C.